Mobility Issues for LVSR

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14. ABSTRACT
The purpose of this analysis was to identify vehicle parameters and terrain features that impede mobility, to forecast mobility over different mission areas of interest, and to identify vehicle parameter modifications that will improve LVSR mobility performance.

15. SUBJECT TERMS
NRMMII, HMMWV, LVS, AAAV, M1A1, M1A2, PLS, and MTVR.

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Standard Form 298 (Rev. 8-98)
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Purpose

- Implement Stochastic Mobility Modeling methodologies that assist in assessing/developing LVSR.

Scope

- Use Stochastic Mobility Modeling to identify vehicle parameters and terrain features that impede mobility.
- Forecast mobility over different mission areas of interest.
- Identify vehicle parameter modifications which will improve LVSR mobility performance.

NRMMII Summary

NRMMII - A computer-based collection of equations and algorithms designed to predict the steady-state operating capability of a given vehicle in a prescribed terrain.

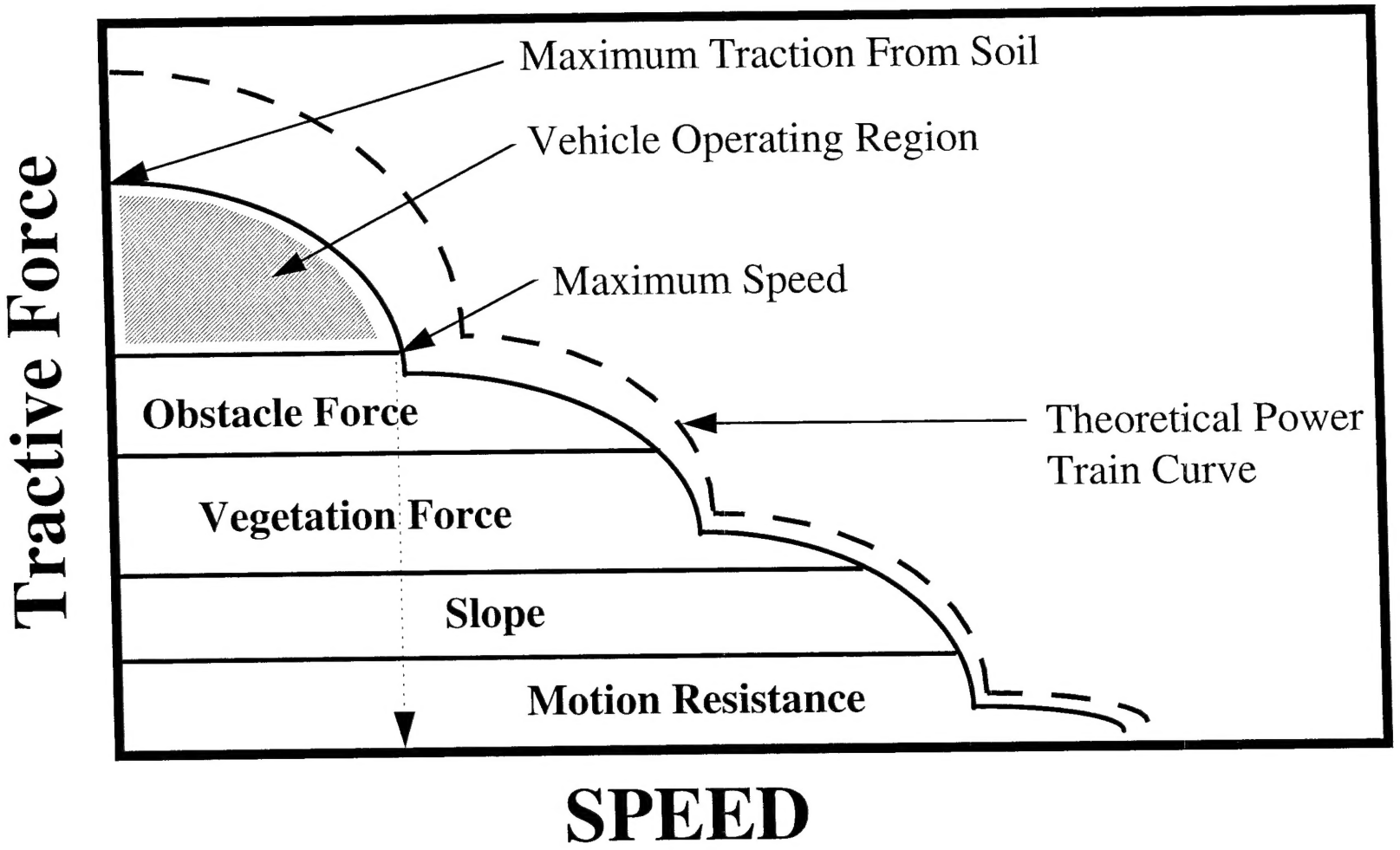
Areas

- Philippines (Mindanao Island)
- South Korea (Eastern Coast)
- Saudi Arabia/Kuwait (Eastern Coast)

Scenarios

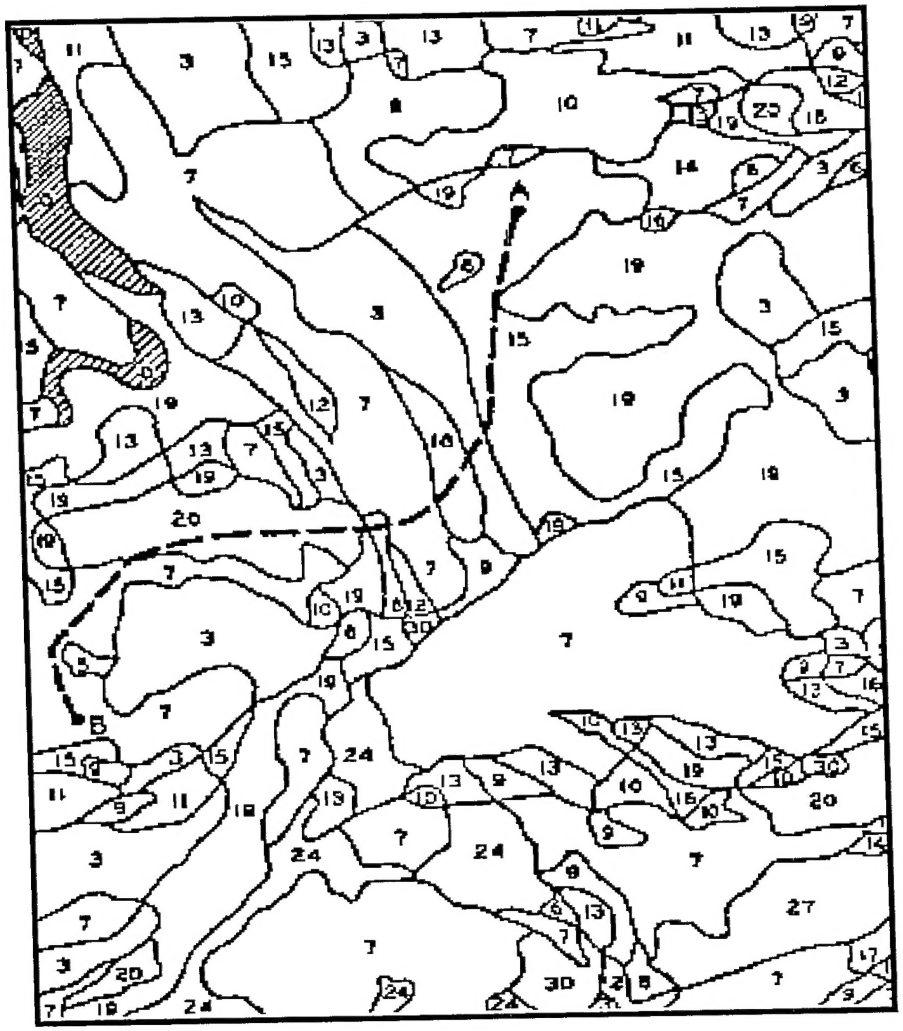
- Dry Normal
  - Average soil strength and moisture for the 30 driest days in an average rainfall year
- Wet Slippery
  - Average soil strength and moisture for the 30 wettest days in an average rainfall year

Tractive Force Speed Curve



Waterways Experiment Station

Terrain Unit Mapping



Terrain Parameters

- Surface Roughness
- Soil Depth to Bedrock
- Road Super-elevation Angle
- Slope Percent
- Obstalce Approach Angle
- Obstacle Height
- Obstacle Length
- Obstacle Spacing
- Obstacle Width
- Soil Strength
- Recognition Distance
- Road Radius of Curvature
- Stem Spacing
- Stem Diameter
- Standing Water Depth

Significant Vehicle Parameters

Vehicle Geometry

ACD	Aerodynamic drag coefficient.
EYEHGT	Driver's eye-height above ground.
PBF	Maximum pushbar force vehicle can withstand overriding vegetation.
PBHT	Height of pushbar above ground.
PFA	Vehicle projected frontal area.
TL	Vehicle length from 1st wheel to last wheel.
VULEN	Length of each vehicle unit.
WDTH	Maximum combination vehicle width.

Power Train

CID	Engine displacement.
FD	Final drive gear ratio and efficiency.
QMAX	Maximum net torque from each engine.
REVM	Tire revolutions per mile for each assembly.
TCASE	Engine to torque-converter gear ratio and efficiency.
TRANS	Transmission gear ratios and efficiencies.
XBRCOF	Combination vehicle braking coefficient.

Traction Components

DFLCT	Tire Deflection for each assembly an deflection case.
DIAW	Undeflected tire diameter for each assembly.
SECTW	Tire nominal section width.
VTIRMX	Maximum tire speed limit for each deflection scenario.

Suspension

VRIDE	Limited speeds for RMS roughness versus limited speed data.
VOOB	Limiting speeds for obstacle height versus 2.5 G limited speed data.

Weight

WGHT	Weight beneath each vehicle assembly.

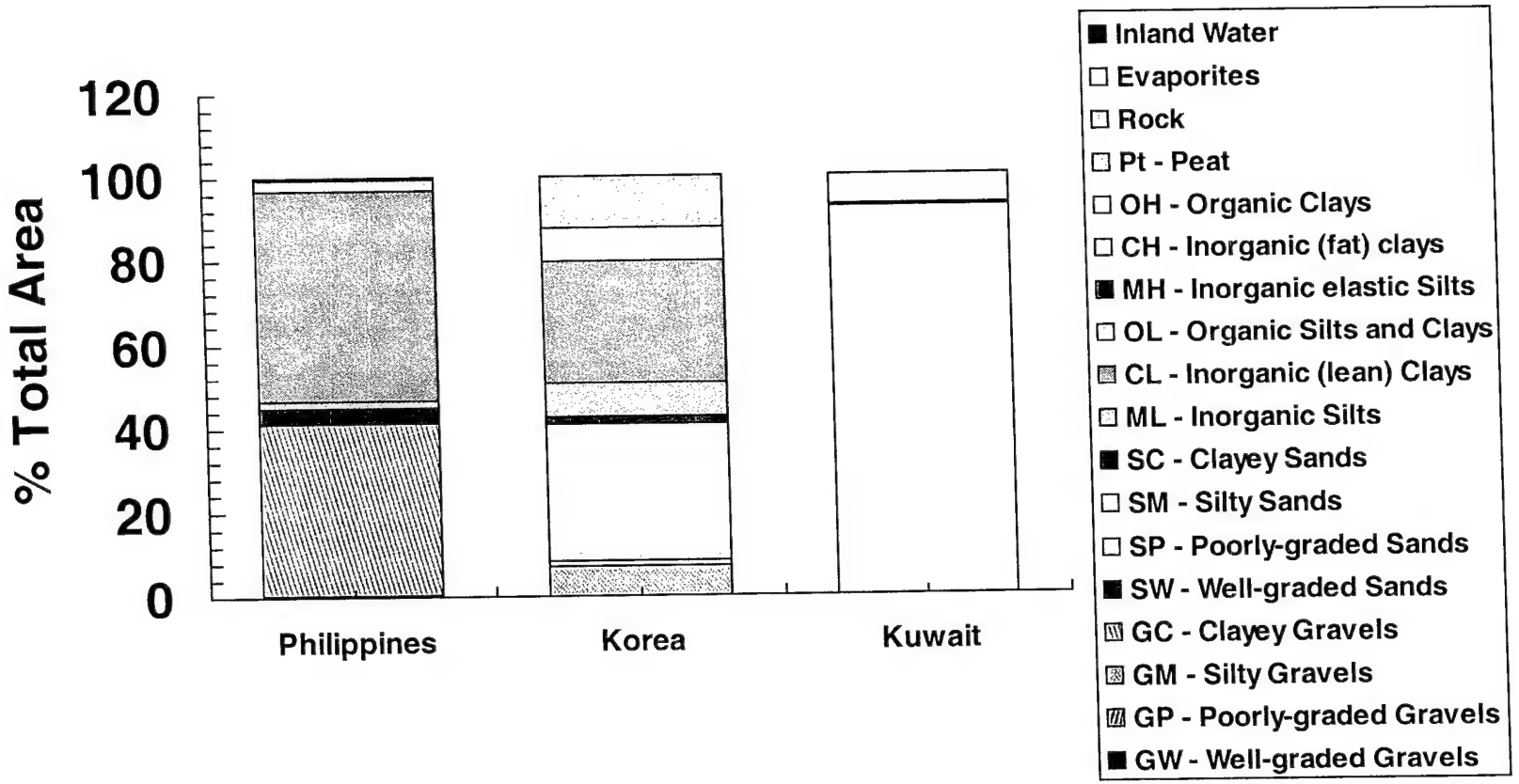
NRMMII "NOGO" Reason Codes

- Visibility
- Soil and Slope Resistance
- Obstacle Clearance Interference
- Obstacle Belly Interference
- Vegetation Override
- Obstacle Override
- Soil NO-GO
- Sliding
- Tipping

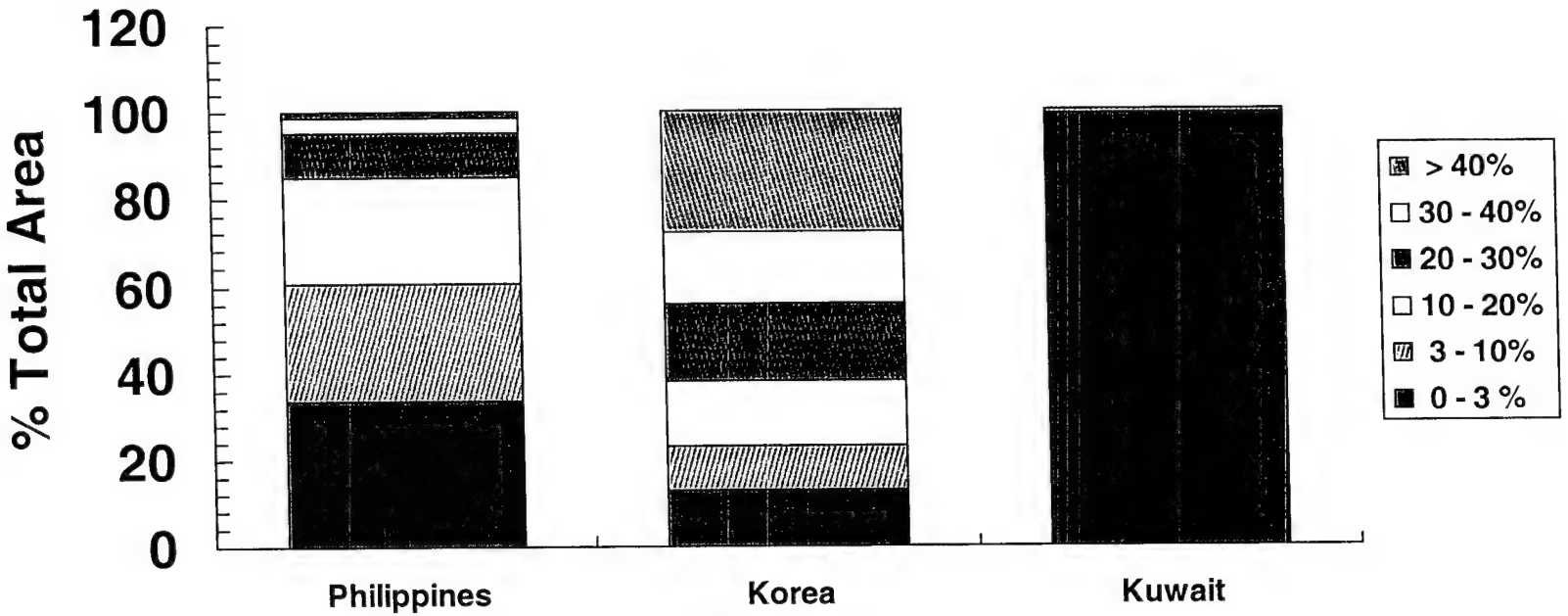
NRMMII "GO" Reason Codes

- Ride Dynamics Limit
- Tire Speed Limit
- Soil, Slope, & Veg Resistance
- Visibility
- Maneuver Around Obst and Veg
- Maneuver Around Veg
- Obstacle Impact Speed
- Obstacle Override Force
- Driver Prudence Over Veg
- Sliding on Curves
- Tipping on Curves

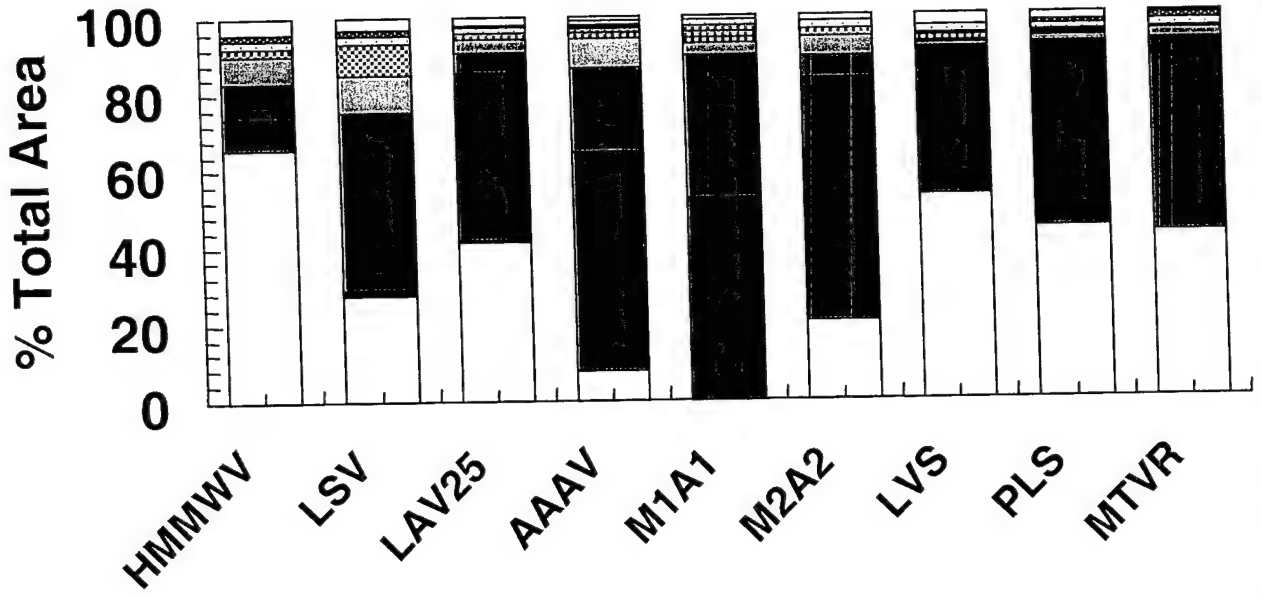
Soil Type Distributions for the Three Study Area



Slope Distributions for the Three Study Areas



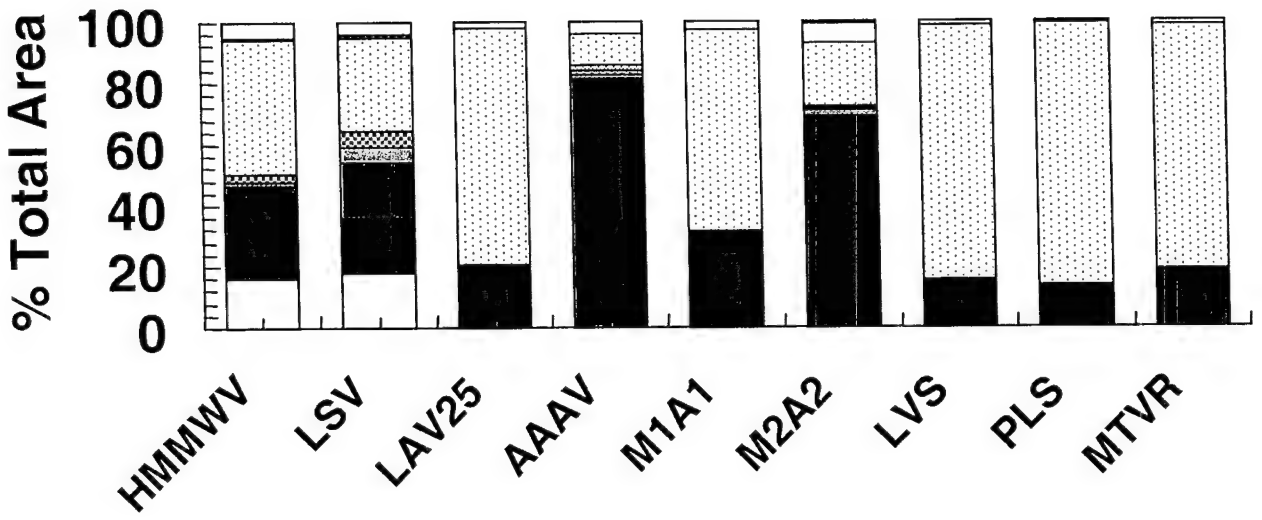
Philippines for Off-Road and Dry-Normal Season (Uniform ±25% Variance)



- Tipping NOGO
- Sliding NOGO
- Soil NOGO
- Obs Override NOGO
- Veg Override NOGO
- Obs Belly Interference NOGO
- Column 18
- Soil & Slope Resistance NOGO
- Inability to Brake NOGO
- Unknown NOGO
- Tipping on Curves
- Sliding on Curves
- AASHO Curvature Spd Limit
- External Limit
- Driver Prudence Over Veg
- Obs Override Force
- Obs Impact Speed
- Mnvr Around Veg
- Mnvr Around Obs & Veg
- Visibility
- Soil,Slope,Veg Resistance
- Tire Speed Limit
- Ride Dynamics Limit
- No Prediction

Waterways Experiment Station

Philippines for Off-Road and Wet-Slippery Season (Uniform ±25% Variance)



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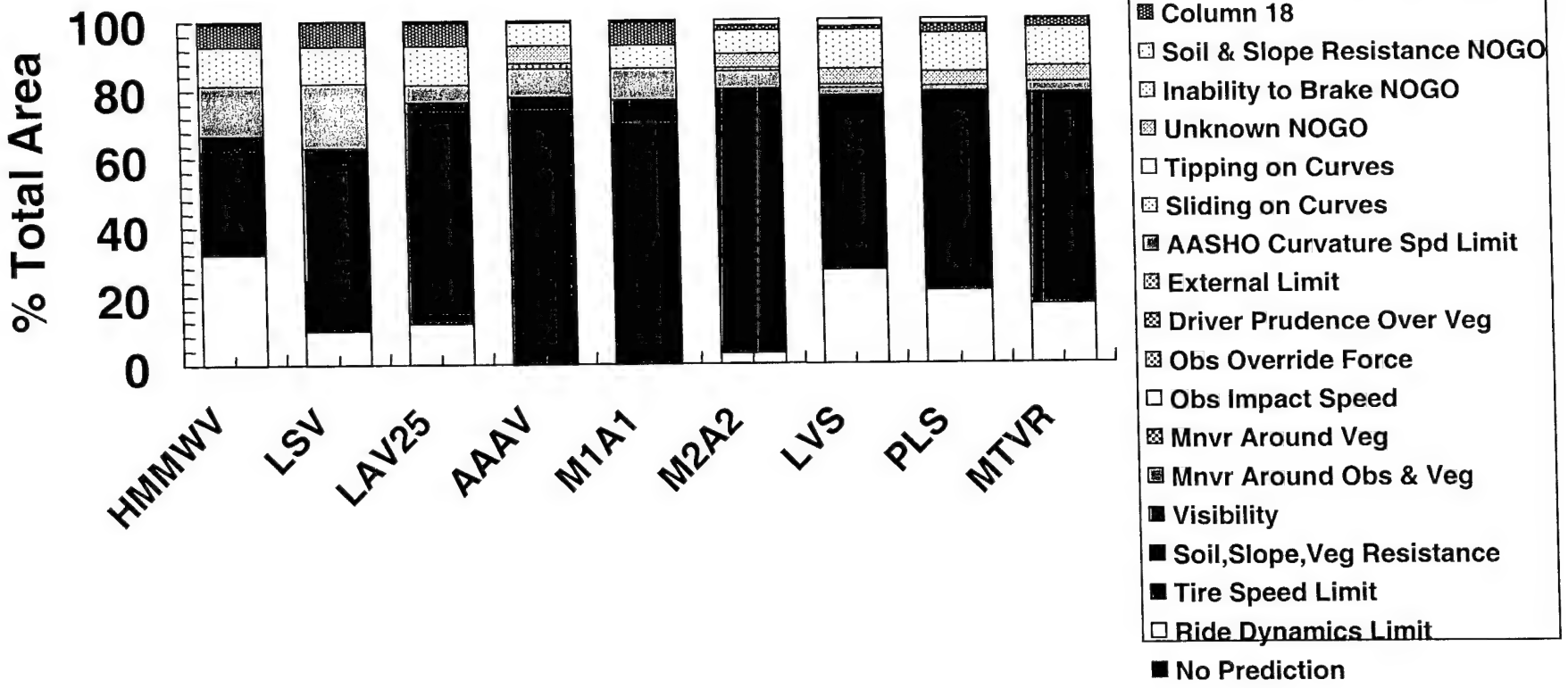
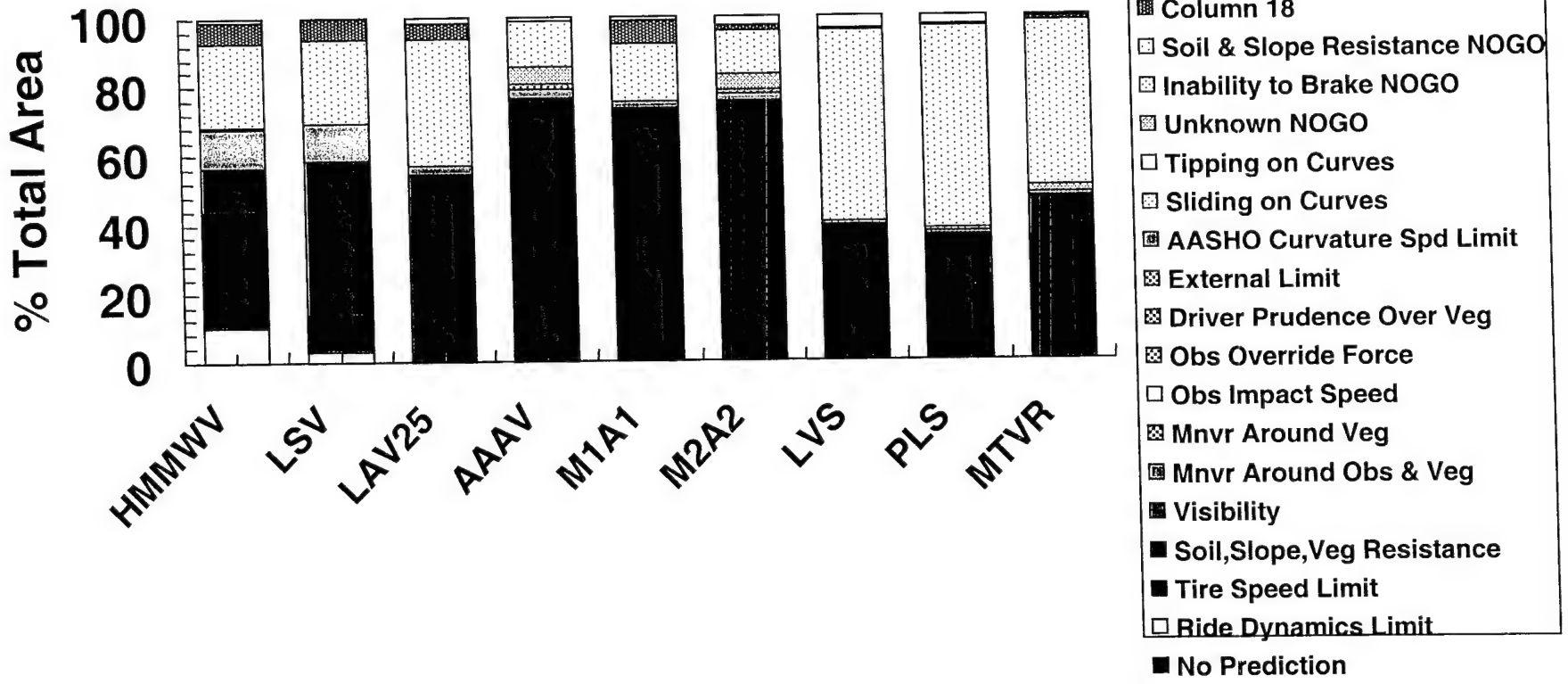
Korea for Off-Road and Dry-Normal Season (Uniform ±25% Variance)



Korea for Off-Road and Wet-Slippery Season (Uniform ±25% Variance)



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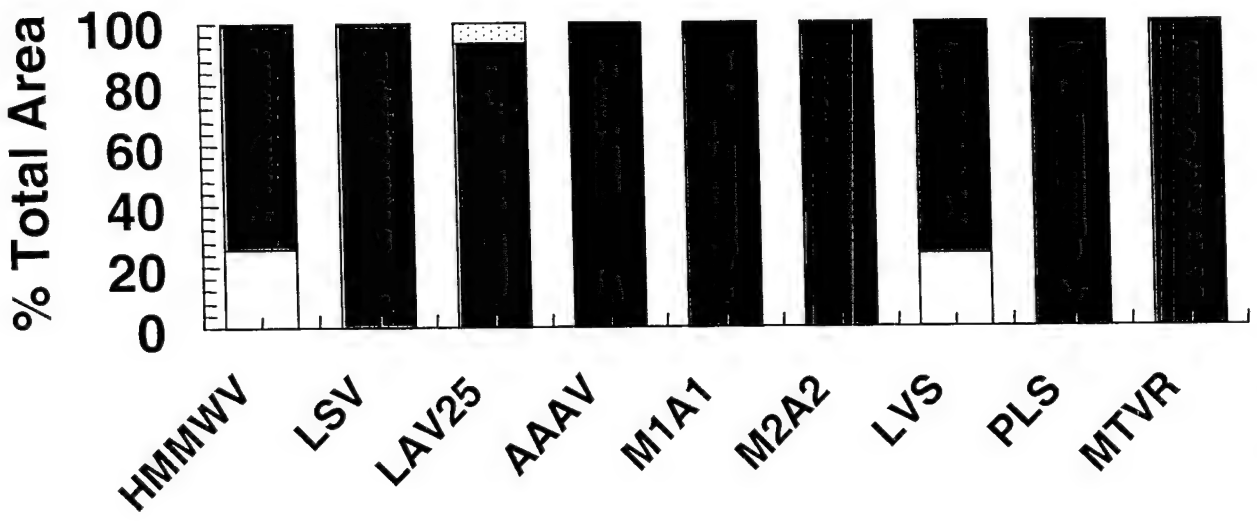
Saudi Arabia/Kuwait for Off-Road and Dry-Normal (Uniform ±25% Variance)



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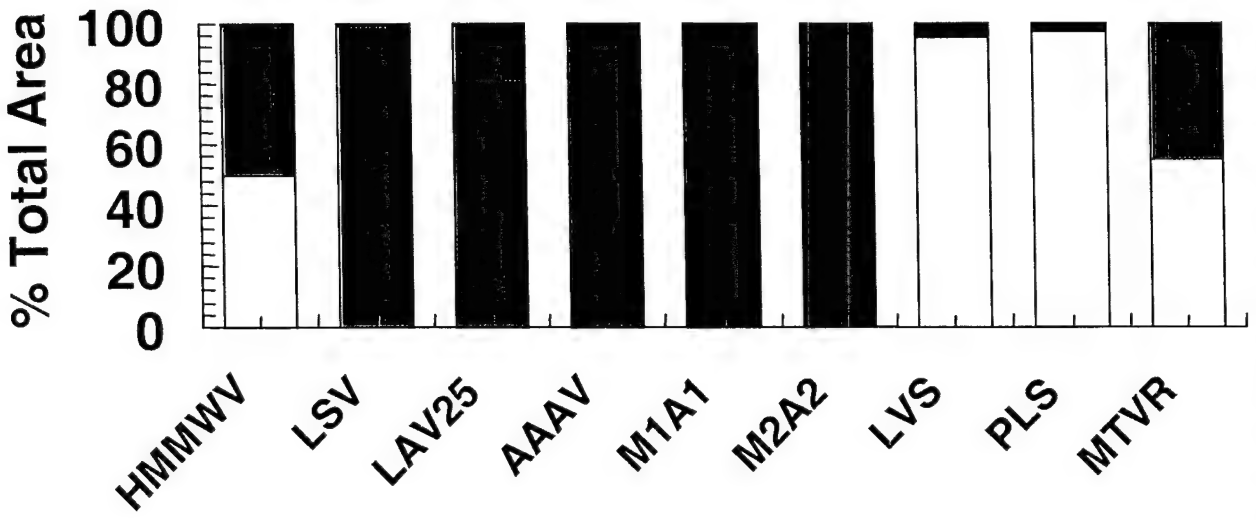
Saudi Arabia/Kuwait for Off-Road and Wet-Slipper (Uniform ±25% Variance)



- Tipping NOGO
- Sliding NOGO
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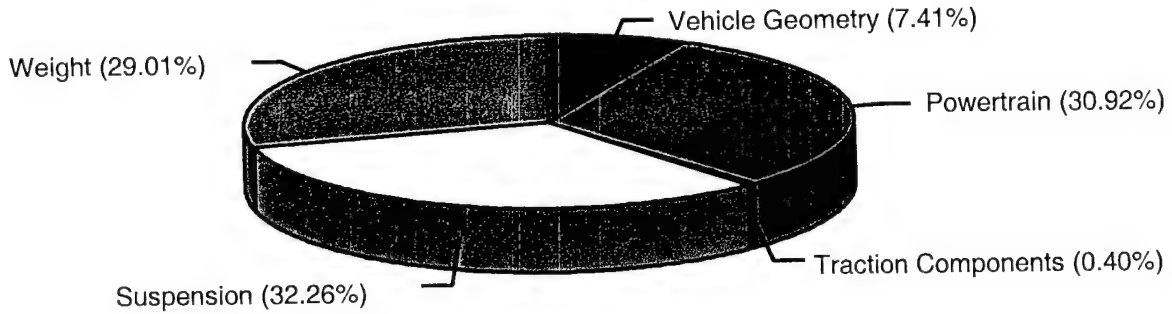
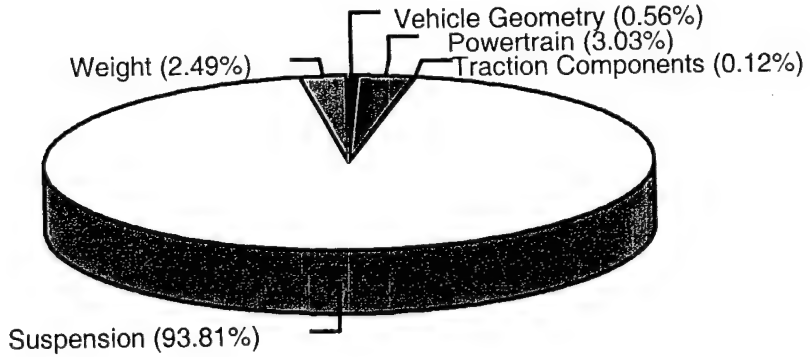
Significant LVS Vehicle Parameters

Philippines, Off-Road, 20% Variance

DRY NORMAL



WET SLIPPERY



Significant LVS Vehicle Parameters

South Korea, Off-Road, 20% Variance

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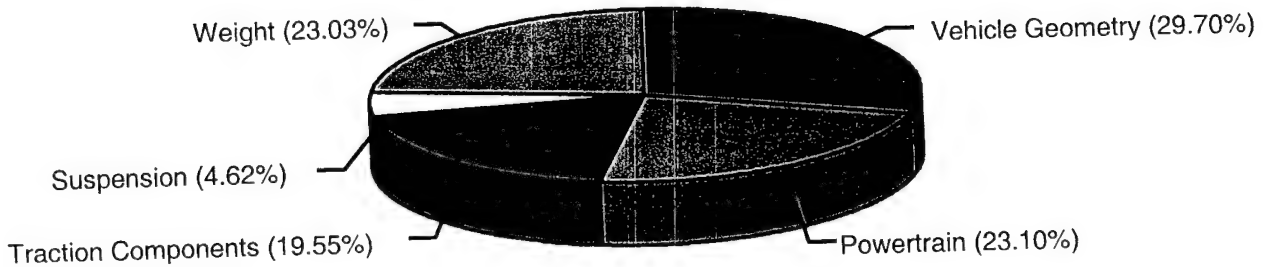

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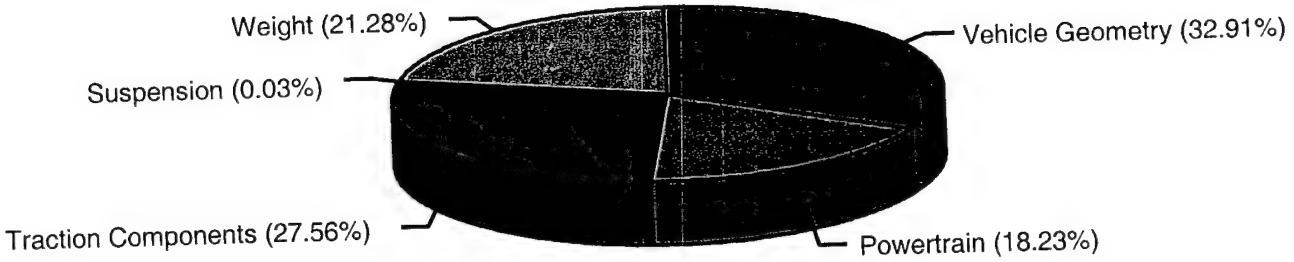
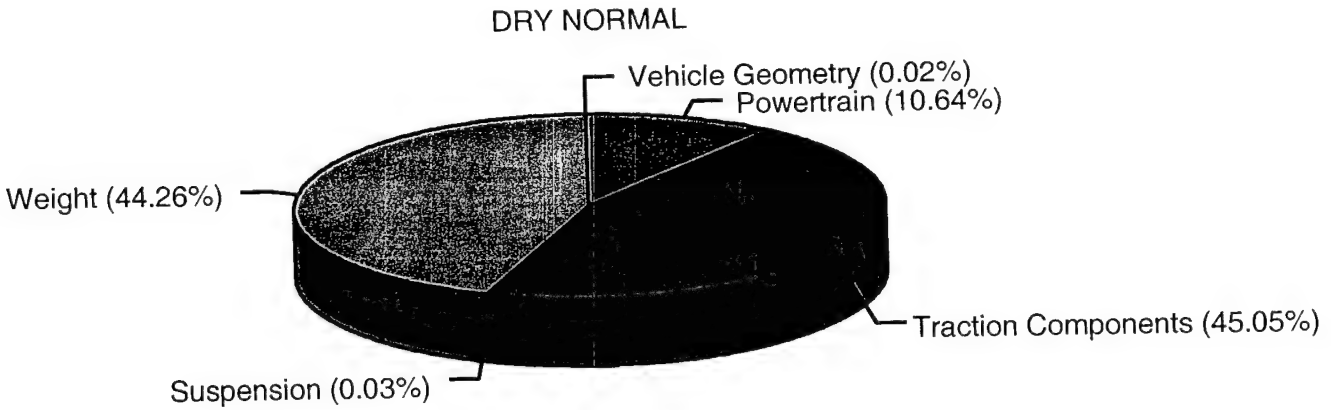
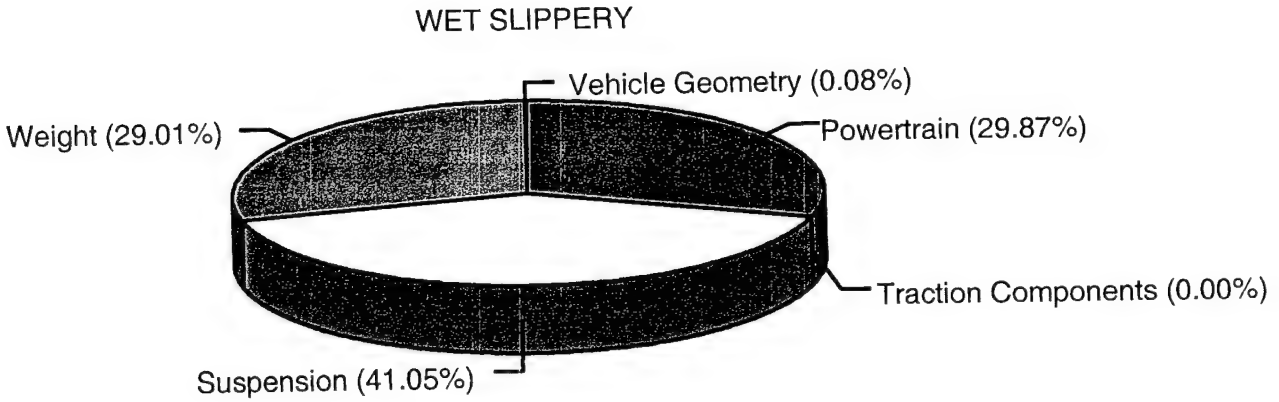


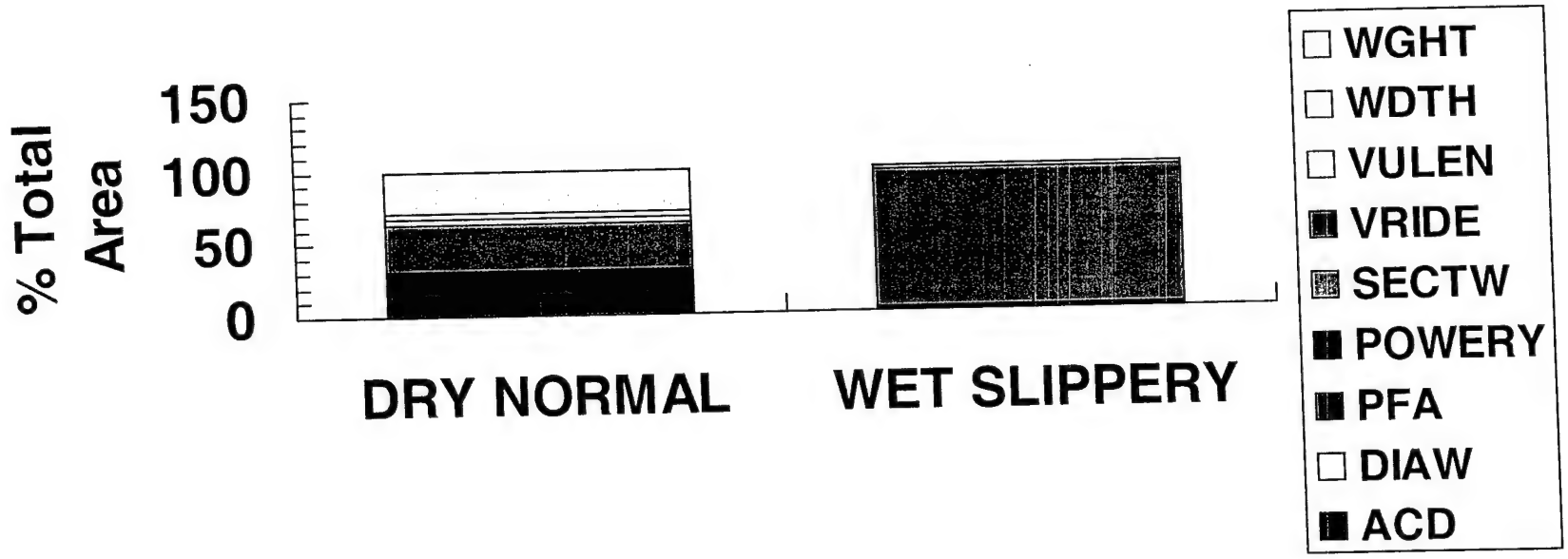
Significant LVS Vehicle Parameters

Kuwait, Off-Road, 20% Variance

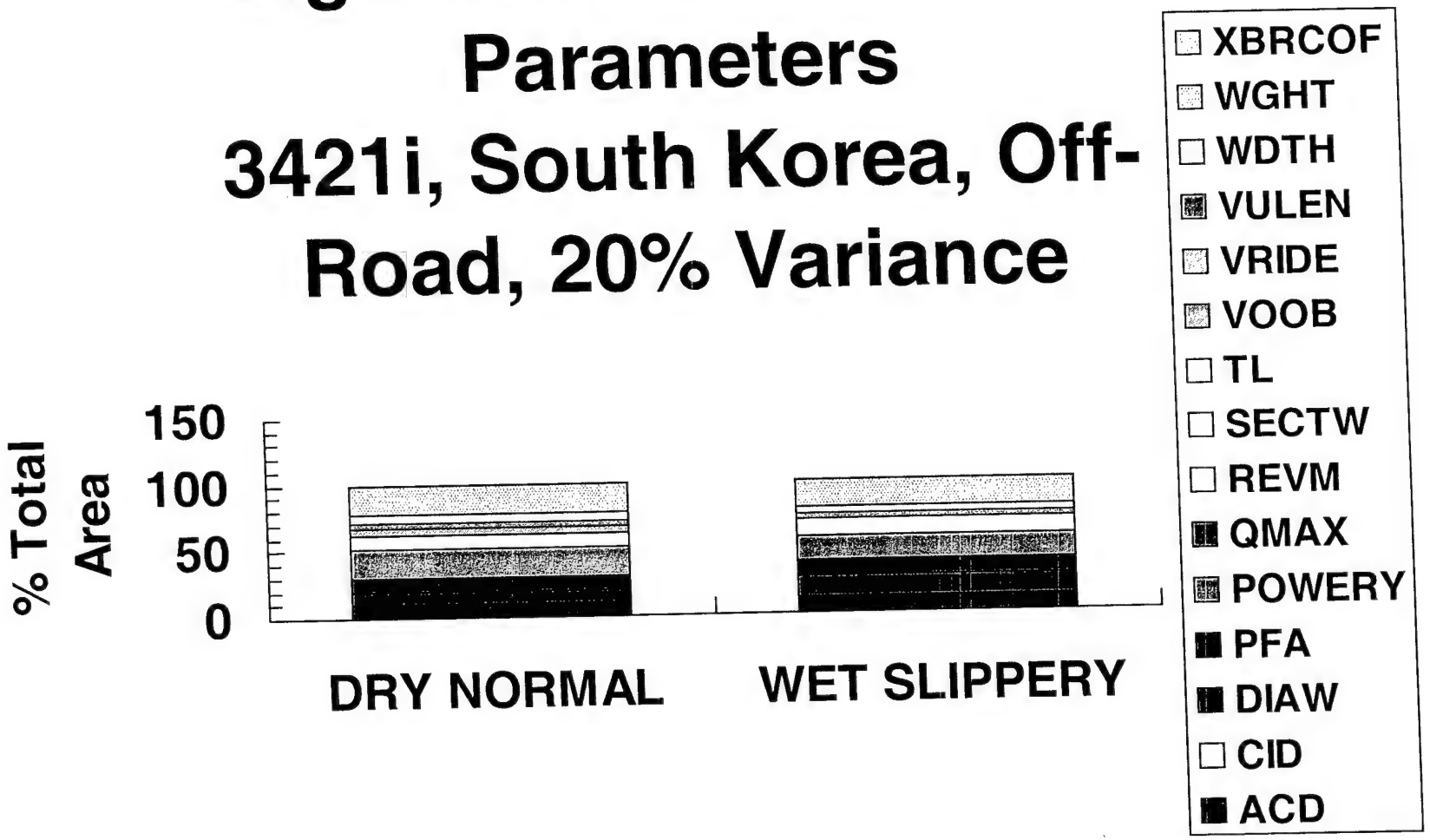




Significant LVS Vehicle Parameters Mindanao, Philippines, Off-Road, 20% Variance

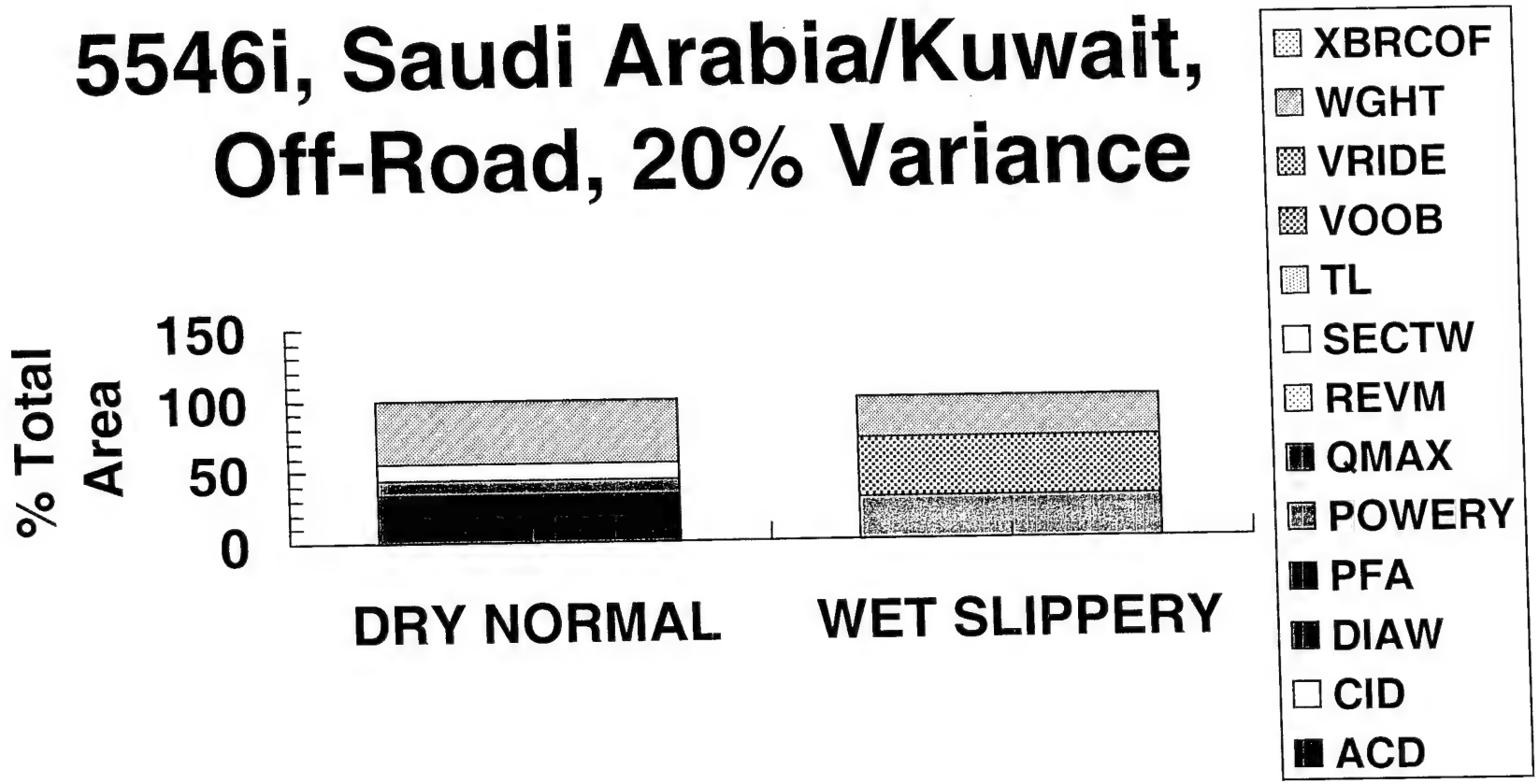


Significant LVS Vehicle Parameters 3421i, South Korea, Off-Road, 20% Variance



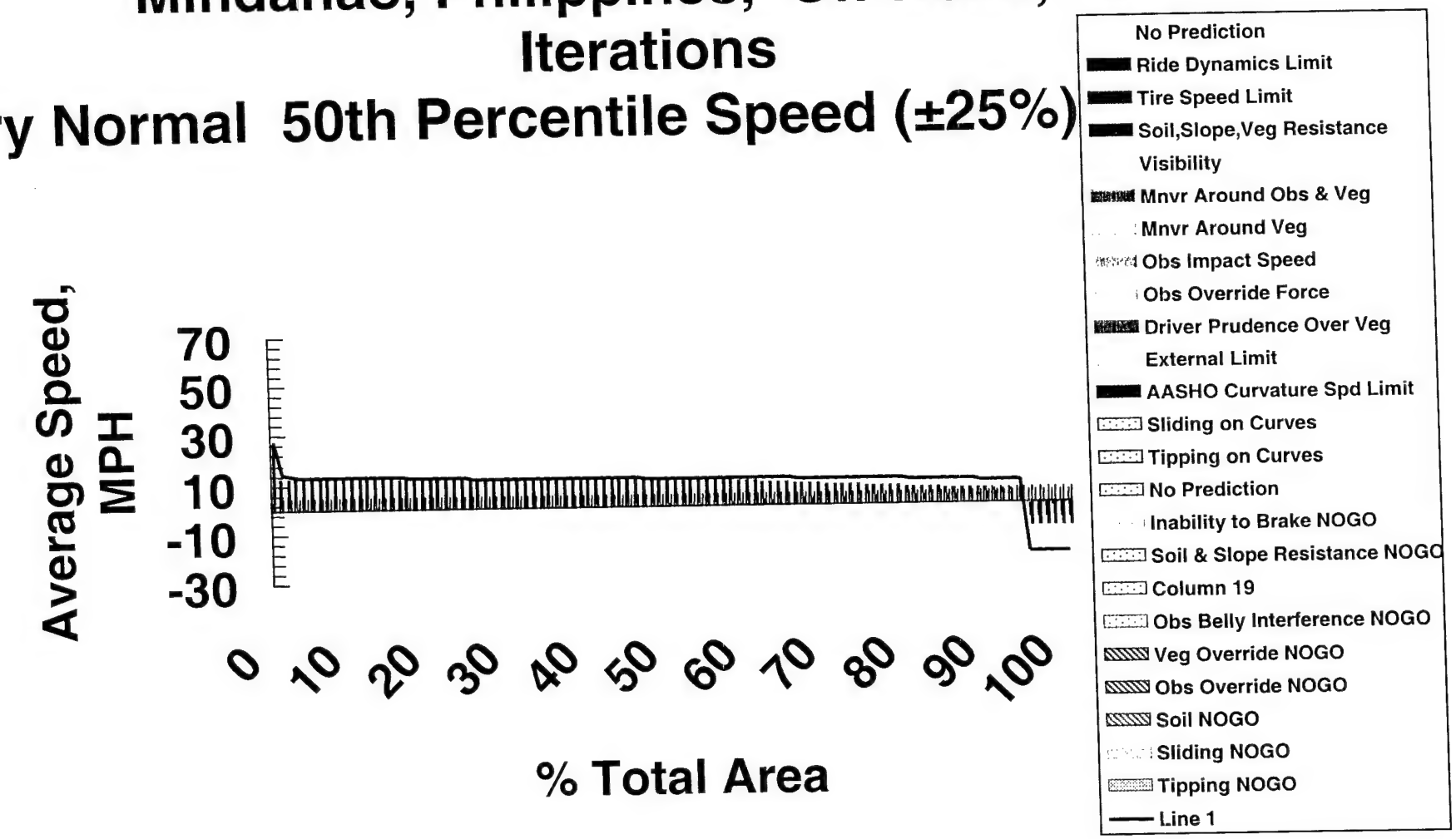
Waterways Experiment Station

Significant LVS Vehicle Parameters 5546i, Saudi Arabia/Kuwait, Off-Road, 20% Variance



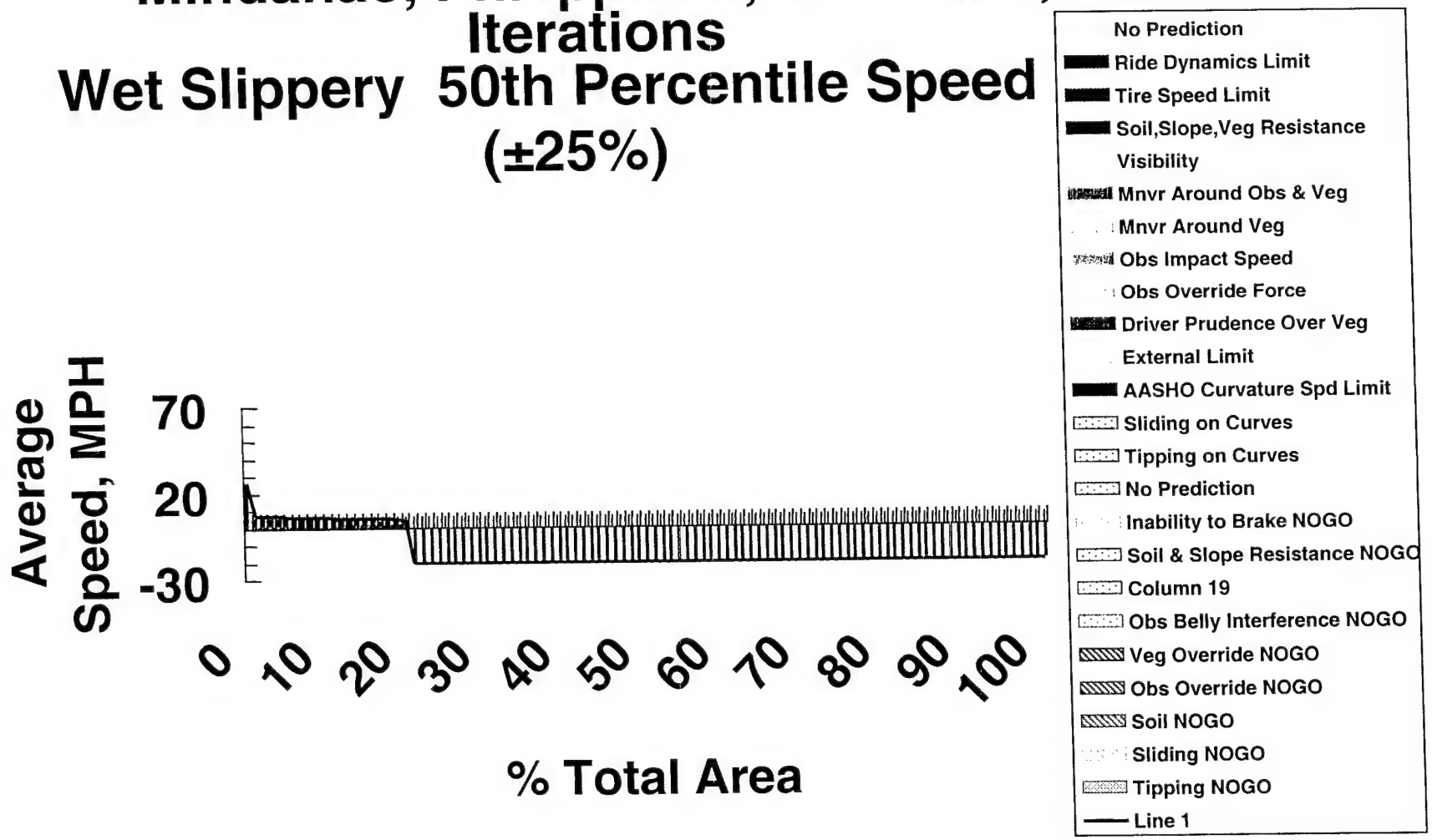
LVS Speed/Reason Profile Mindanao, Philippines, Off-Road, 100 Iterations

Dry Normal 50th Percentile Speed (±25%)



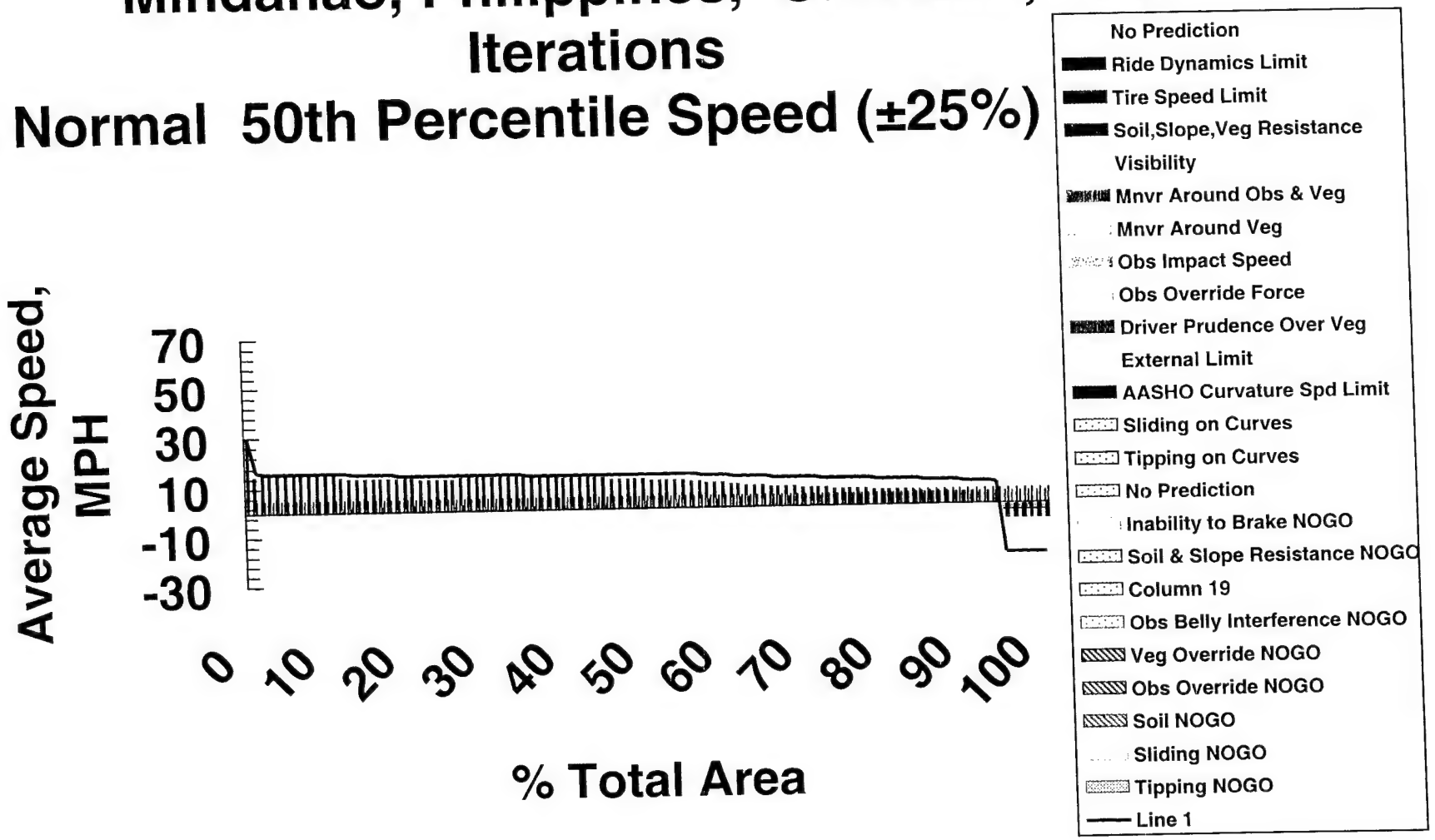
Waterways Experiment Station

LVS Speed/Reason Profile Mindanao, Philippines, Off-Road, 100 Iterations Wet Slippery 50th Percentile Speed (±25%)



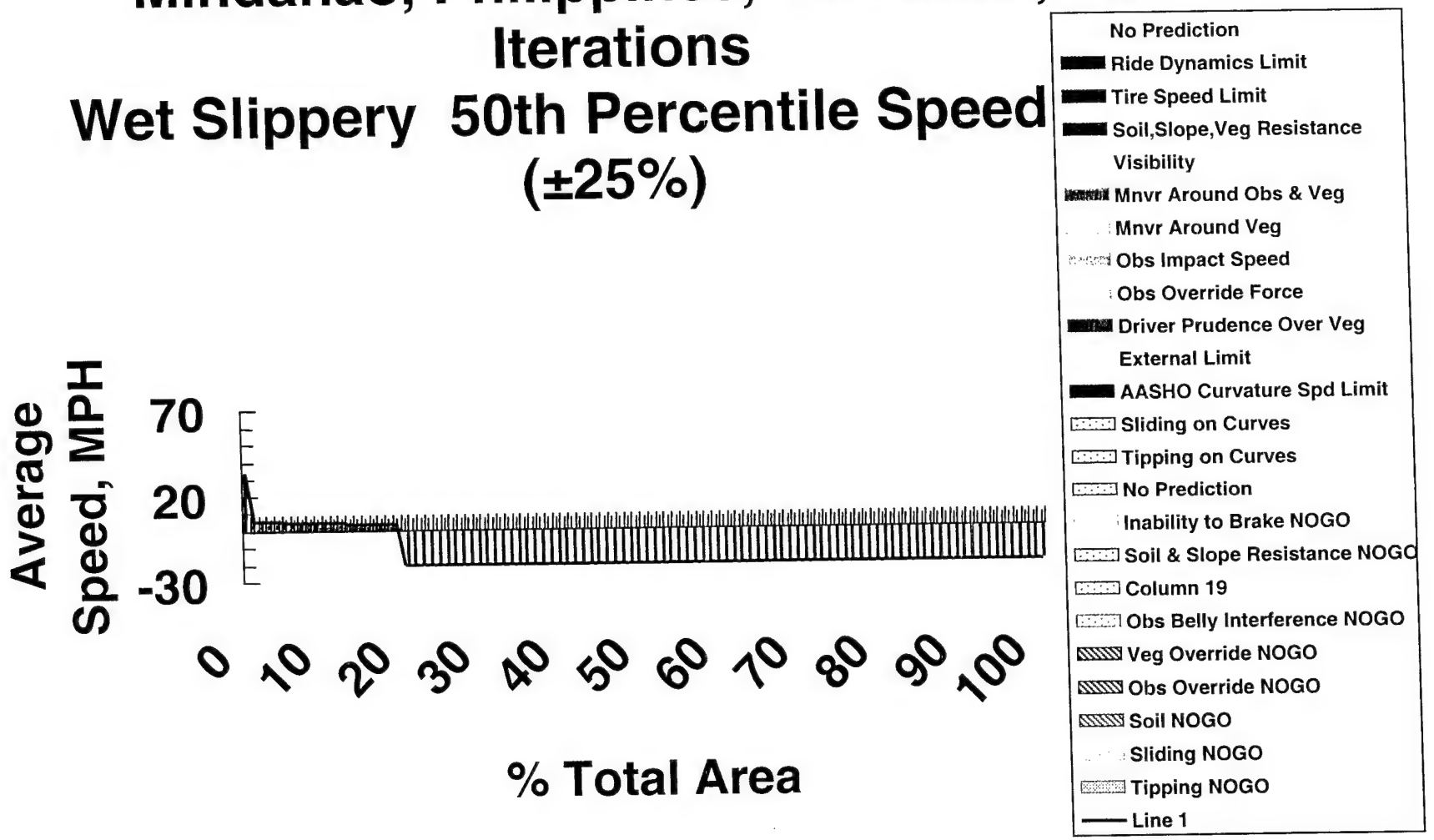
PLS Speed/Reason Profile Mindanao, Philippines, Off-Road, 100 Iterations

Dry Normal 50th Percentile Speed (±25%)



Waterways Experiment Station

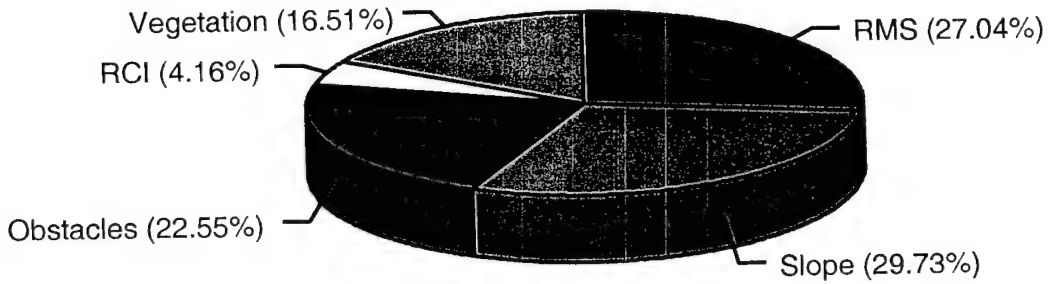
PLS Speed/Reason Profile Mindanao, Philippines, Off-Road, 100 Iterations Wet Slippery 50th Percentile Speed (±25%)



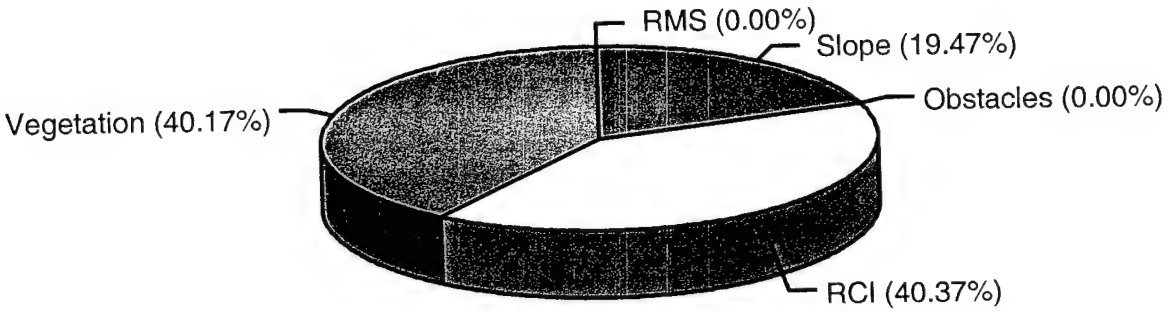
Significant Terrain Parameters for LVS

Philippines, Off-Road, 25% Variance

DRY NORMAL



WET SLIPPERY



Significant Terrain Parameters for LVS

Korea, Off-Road, 25% Variance

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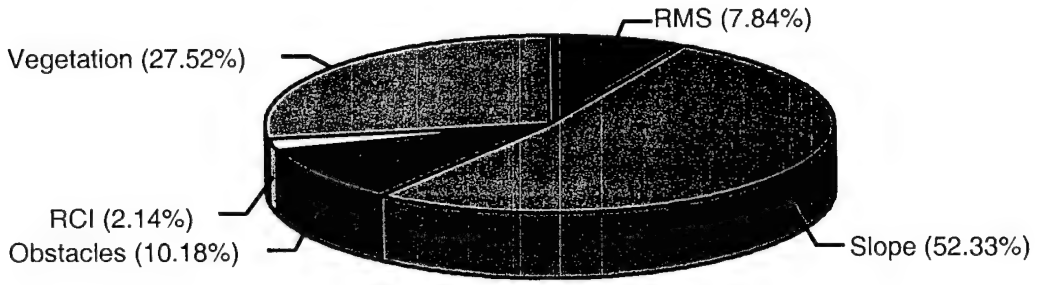

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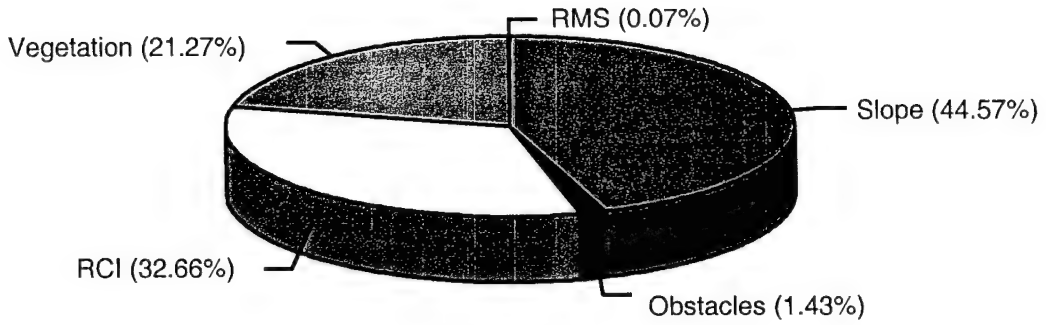
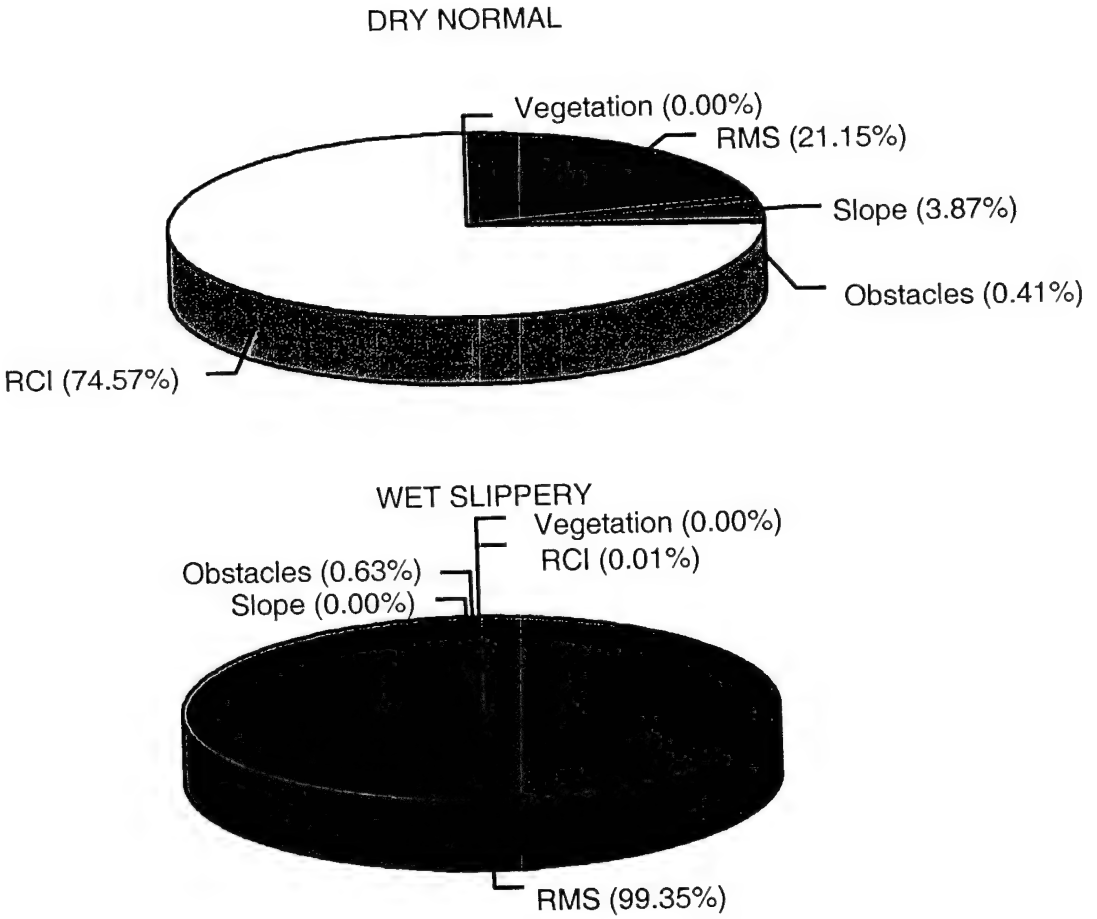
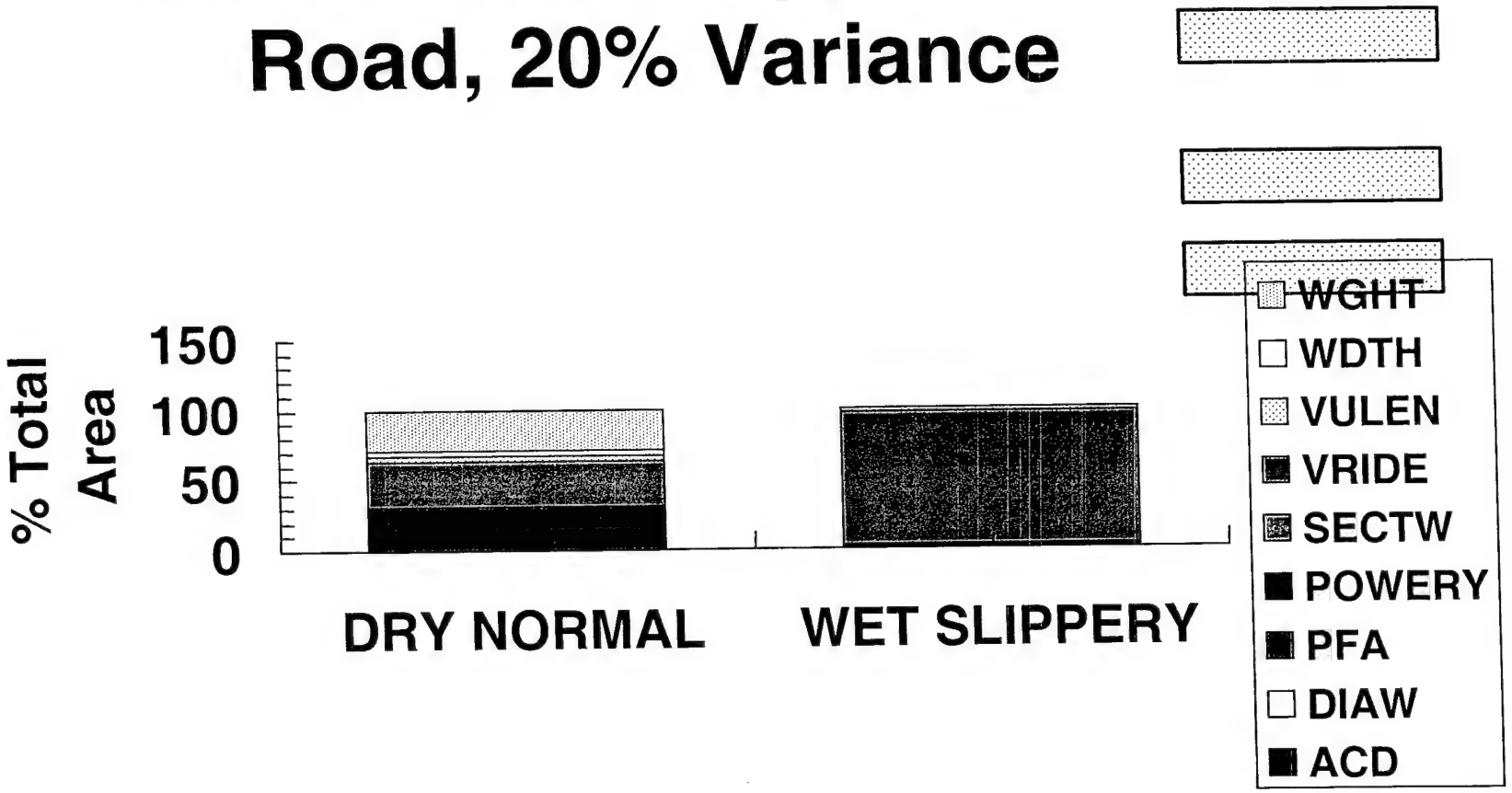


Significant Terrain Parameters for LVS

Kuwait, Off-Road, 25% Variance



Significant LVS Vehicle Parameters Mindanao, Philippines, Off-Road, 20% Variance



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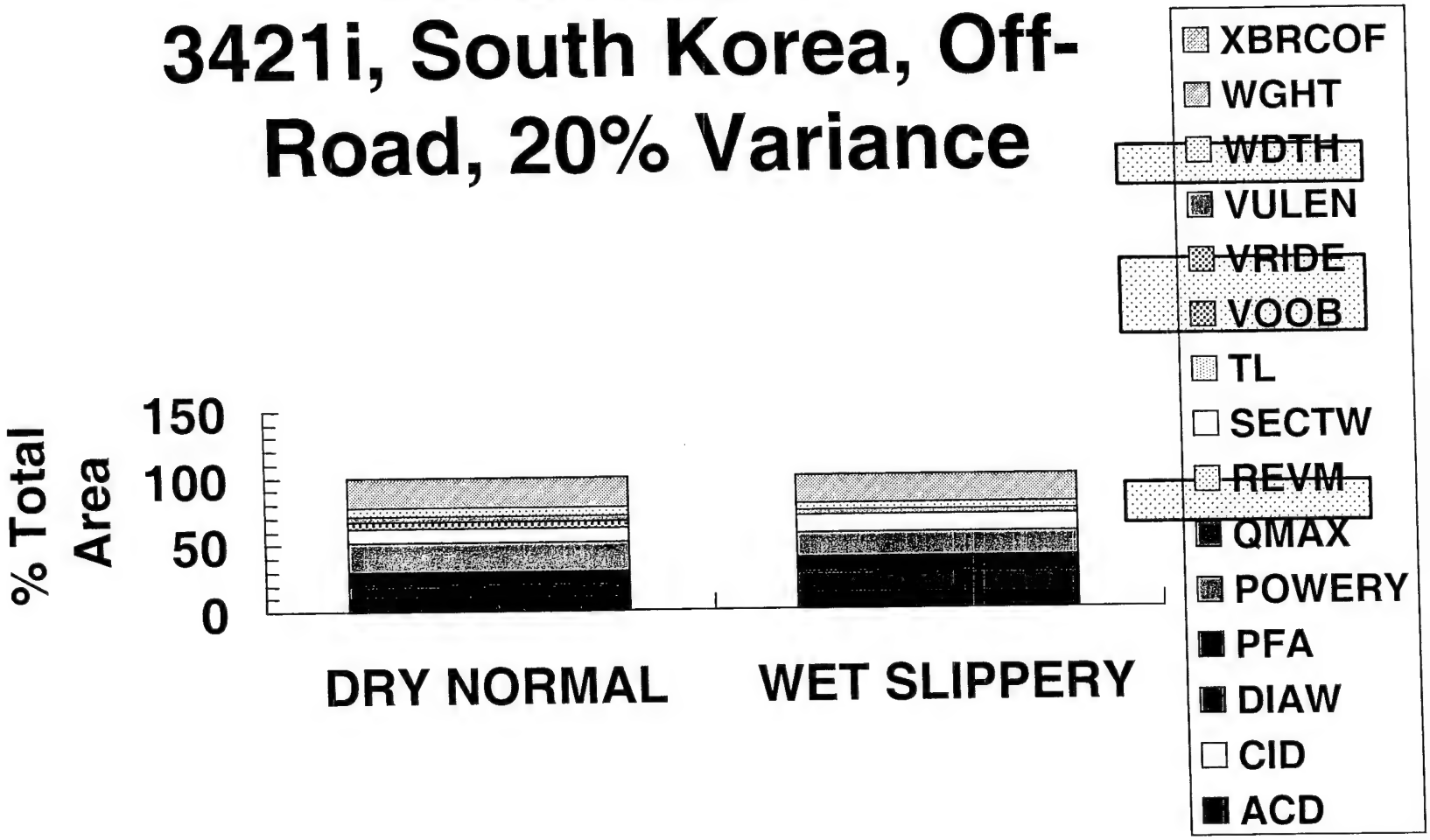

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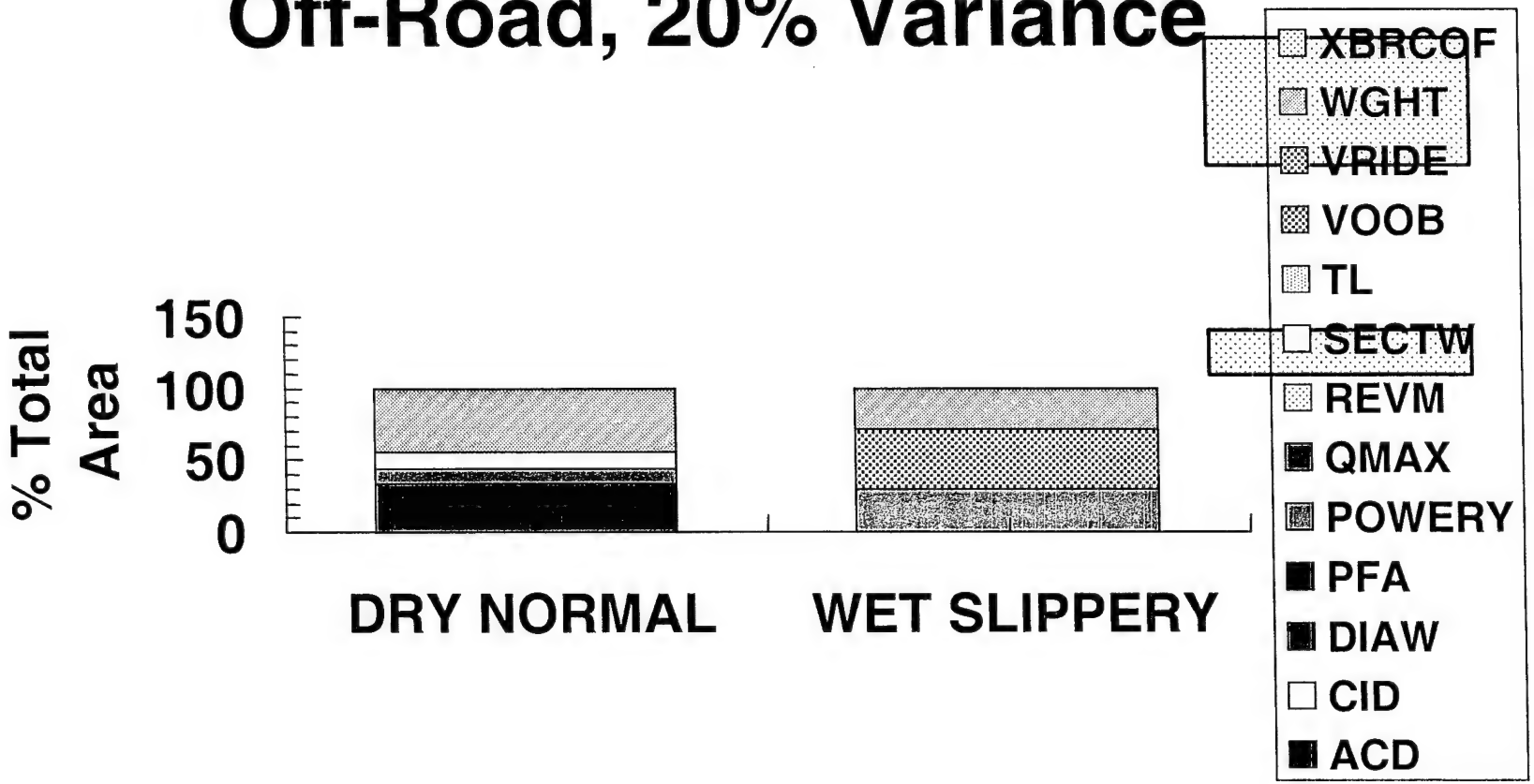
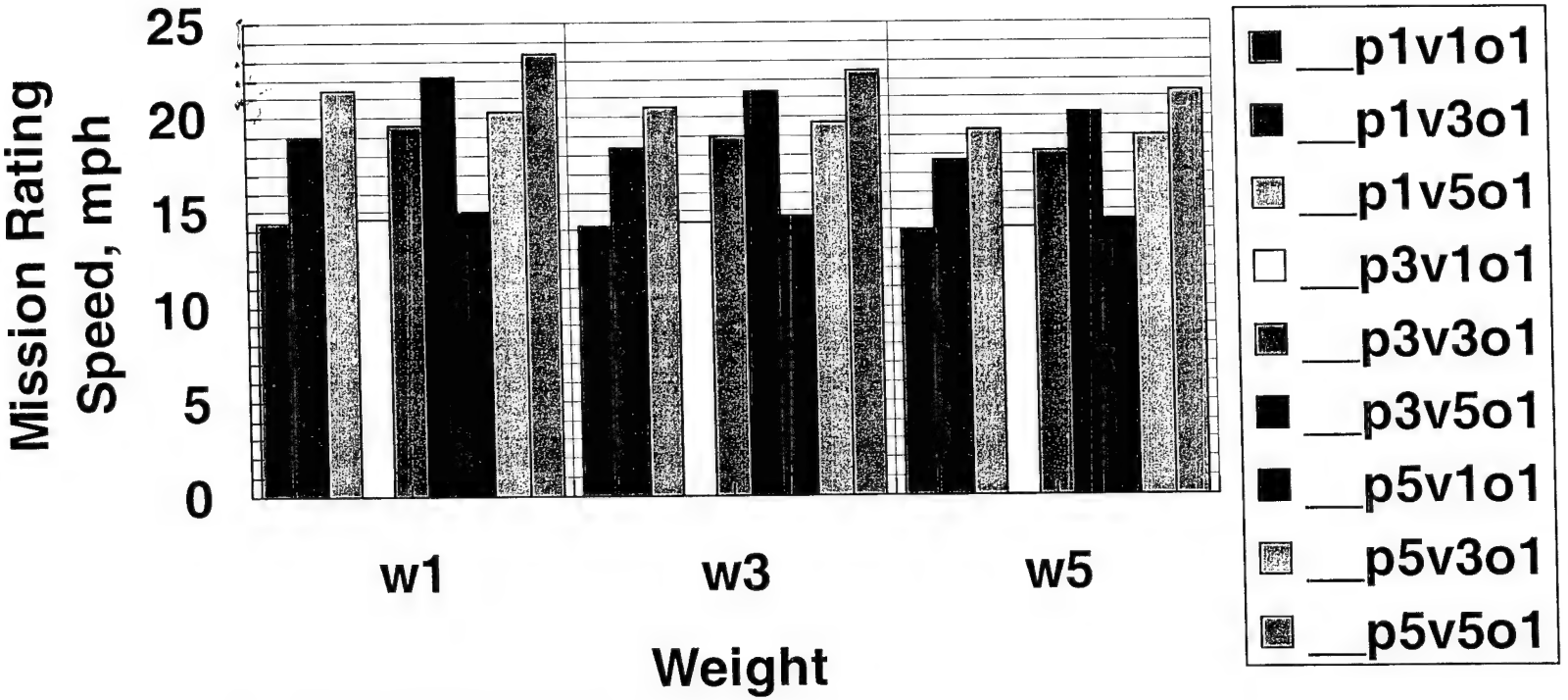


LVSR Mission Percentages

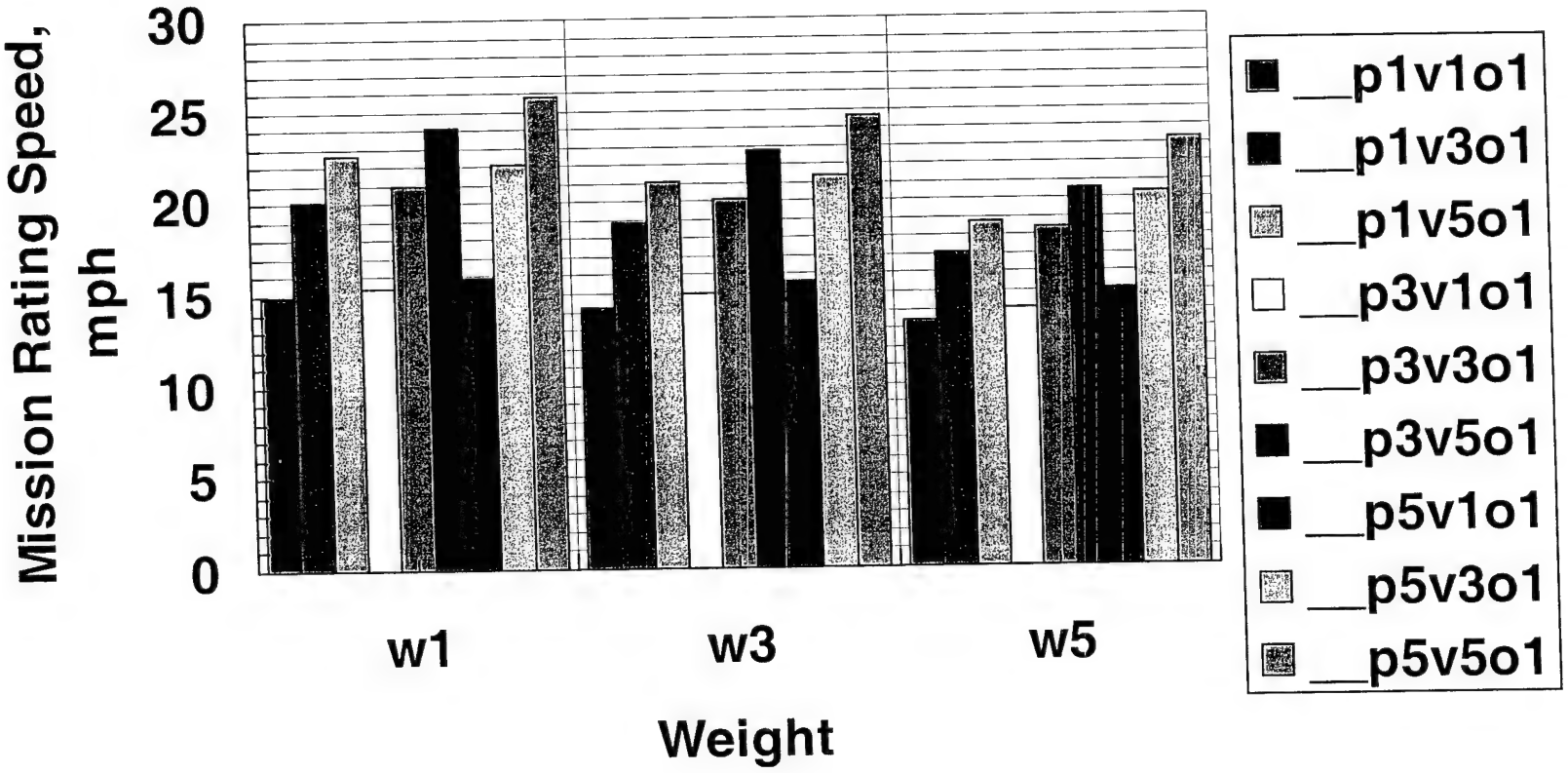
Percent of "Best" Terrain/Road Units					Percent Total Operating Distance on			
Primary Roads	Secondary Roads	Trails	Off-Road		Primary Roads	Secondary Roads	Trails	Off-Road
Philippines								
10	20	30	40		100	100	90	80
Korea								
10	20	30	40		100	100	90	76
Kuwait								
10	20	30	40		100	100	90	80

LVSR MSR Performance in the Philippines



Payload Weight	Engine Power	Suspension (Ride)	Suspension (Shock)
w1 = 12.5 ton	p1 = 445 hp	v1 = standard	o1 = standard
w3 = 16.5 ton	p3 = 500 hp	v3 = improved standard	
w5 = 22.5 ton	p5 = 600 hp	v5 = independent	

LVSR MSR Performance in Korea



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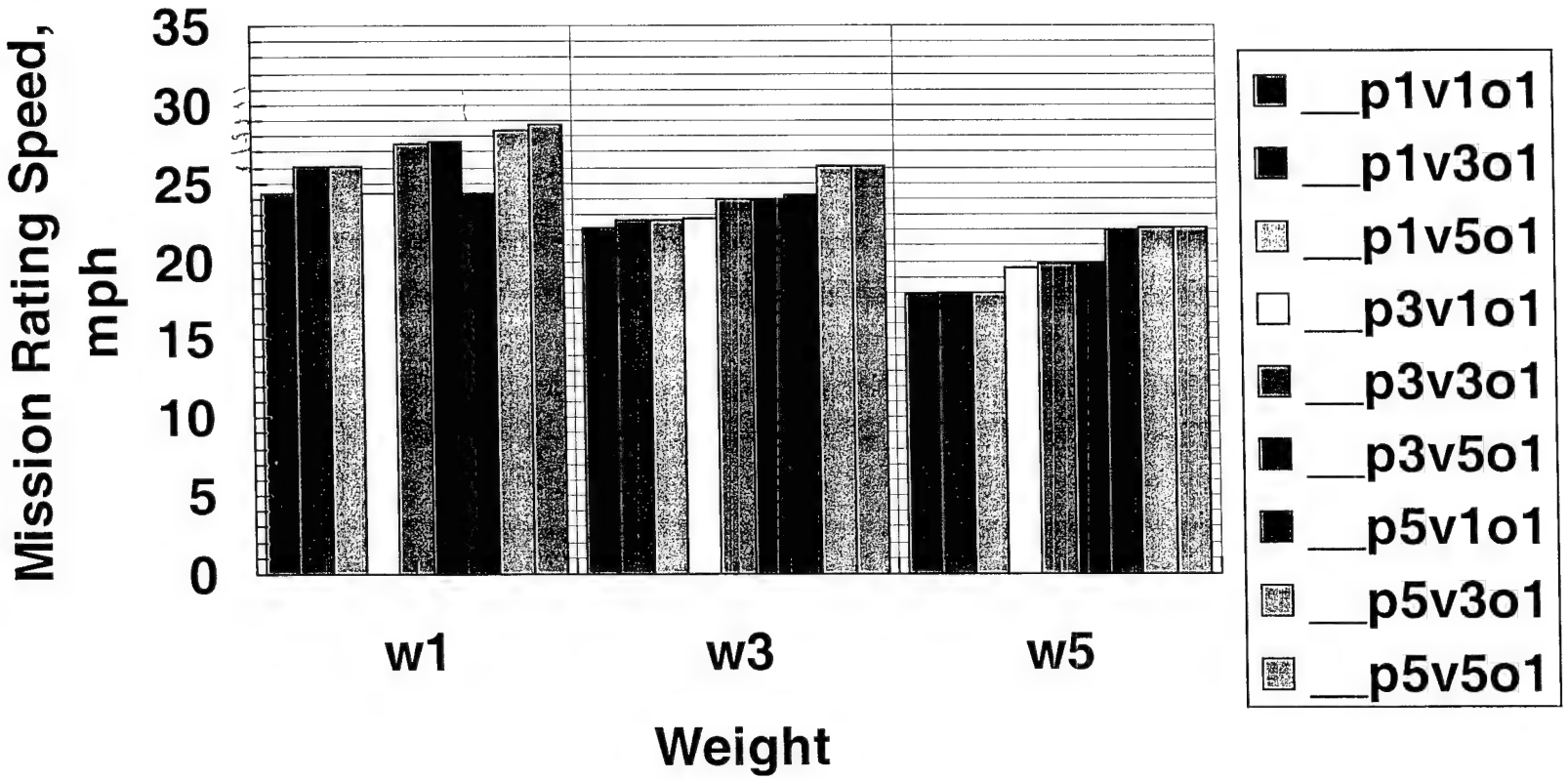
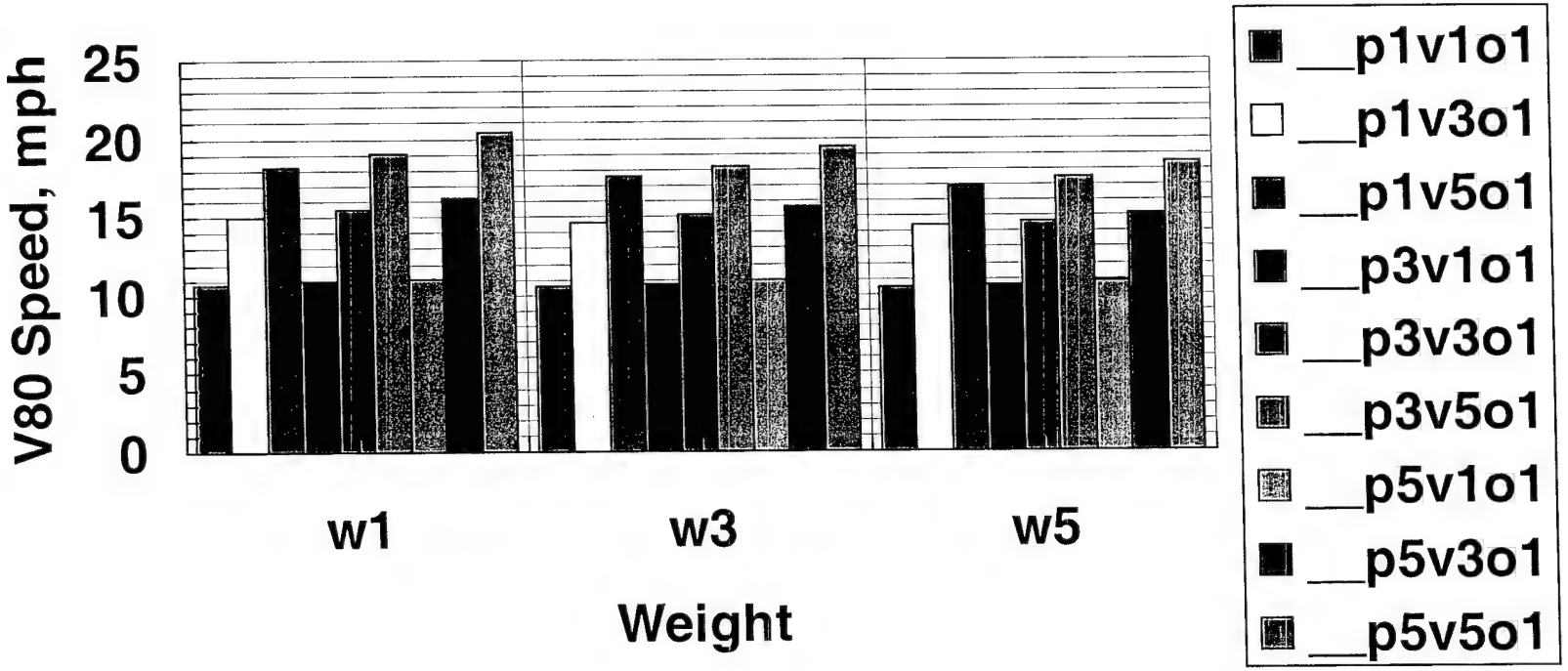
w5 = 22.5 ton	p5 = 600 hp	v5 = independent	

LVSR MSR Performance in Kuwait



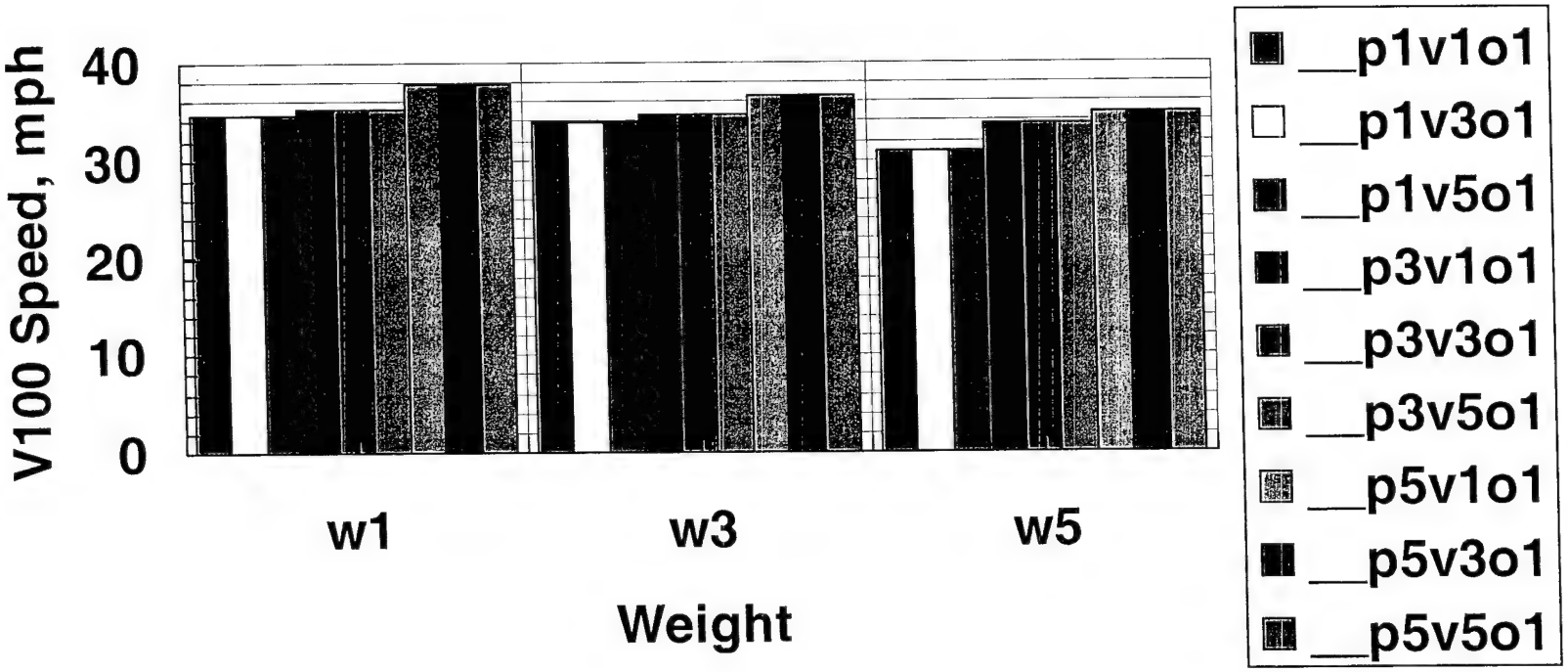
Payload Weight	Engine Power	Suspension (Ride)	Suspension (Shock)
w1 = 12.5 ton	p1 = 445 hp	v1 = standard	o1 = standard
w3 = 16.5 ton	p3 = 500 hp	v3 = improved standard	
w5 = 22.5 ton	p5 = 600 hp	v5 = independent	

LVSR Speed Performance in the Philippines Off-Road



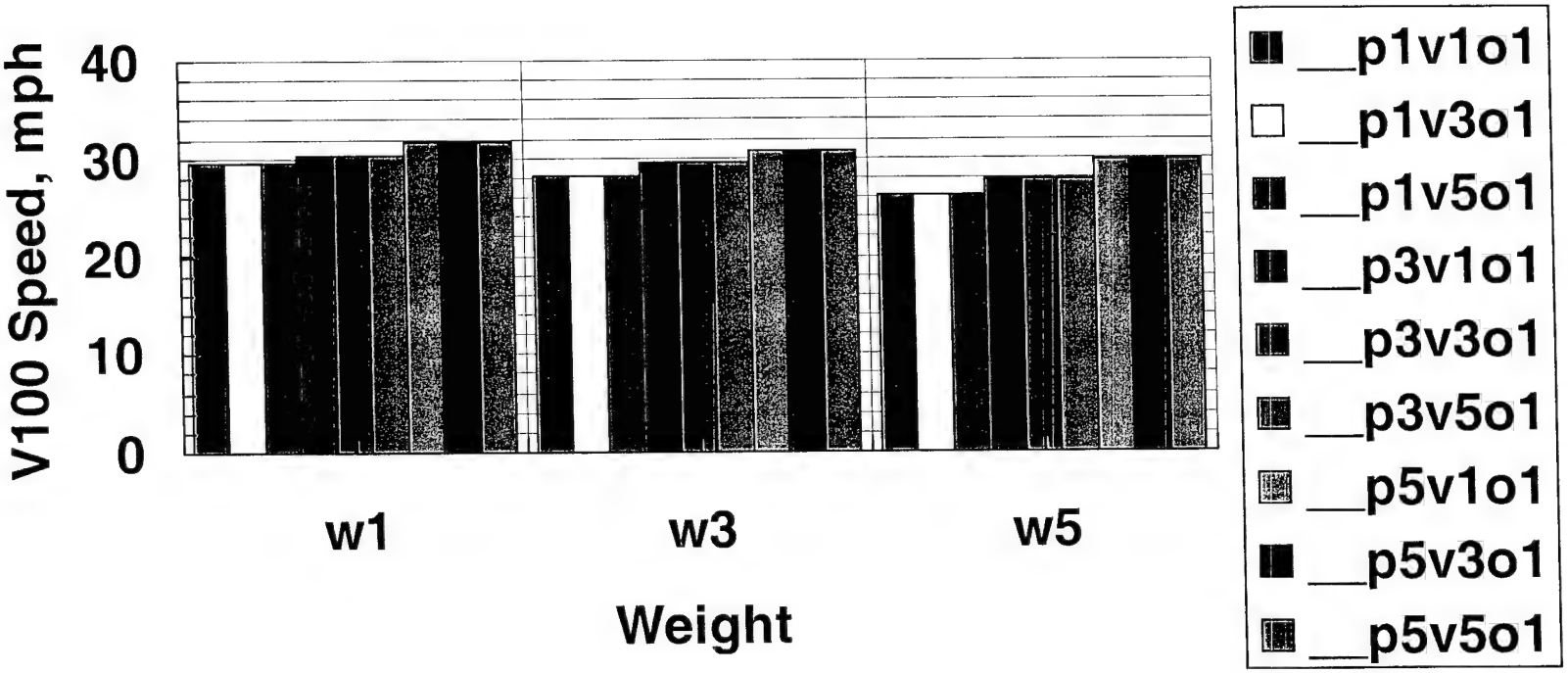
Payload Weight	Engine Power	Suspension (Ride)	Suspension (Shock)
w1 = 12.5 ton	p1 = 445 hp	v1 = standard	o1 = standard
w3 = 16.5 ton	p3 = 500 hp	v3 = improved standard	
w5 = 22.5 ton	p5 = 600 hp	v5 = independent	

LVSR Speed Performance in the Philippines Primary Roads



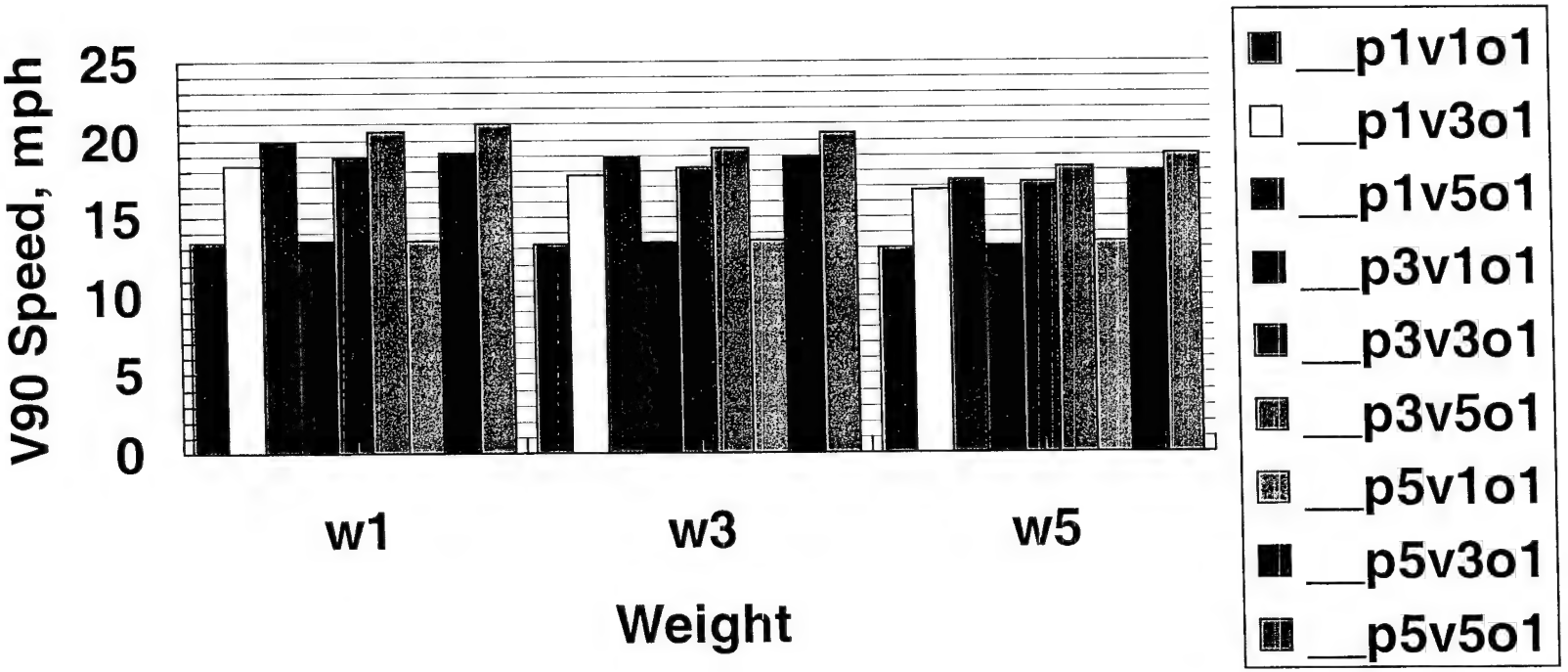
Payload Weight	Engine Power	Suspension (Ride)	Suspension (Shock)
w1 = 12.5 ton	p1 = 445 hp	v1 = standard	o1 = standard
w3 = 16.5 ton	p3 = 500 hp	v3 = improved standard	
w5 = 22.5 ton	p5 = 600 hp	v5 = independent	

LVSR Speed Performance in the Philippines Secondary Roads



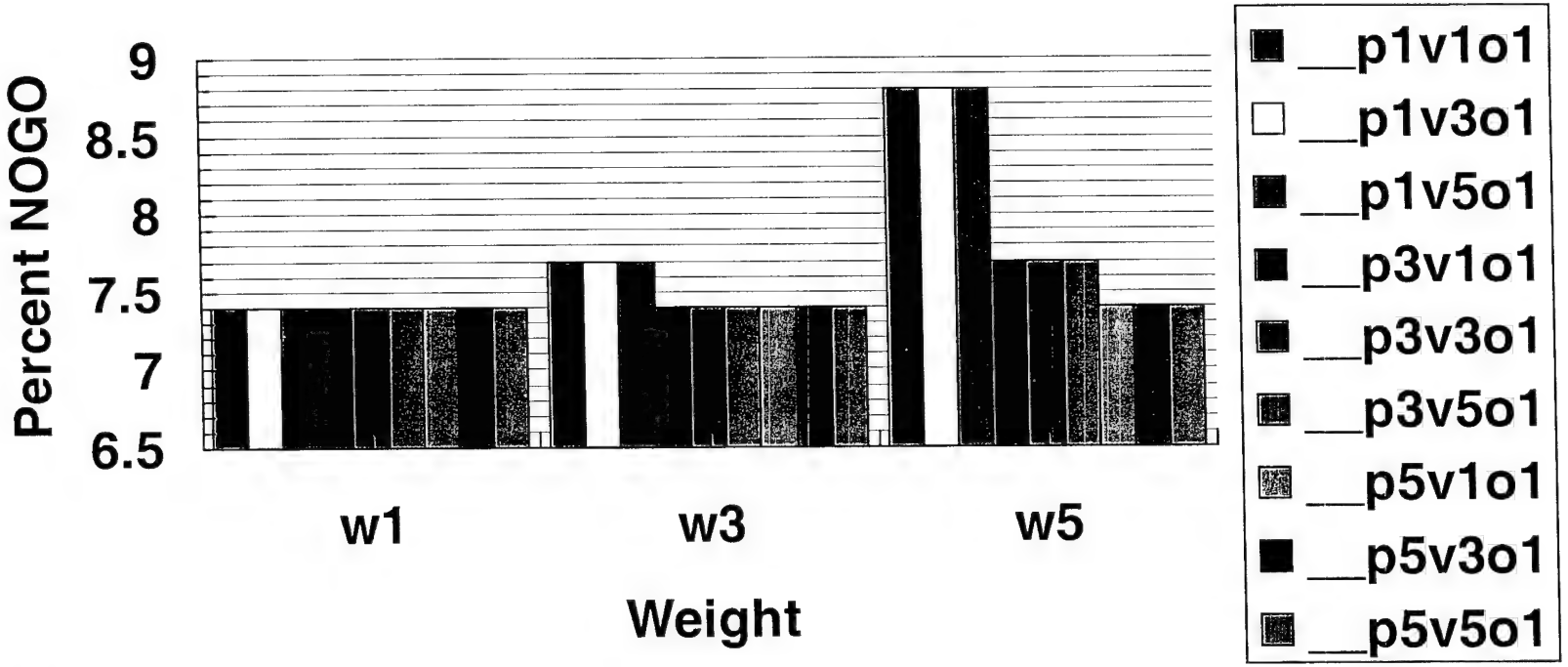
Payload Weight	Engine Power	Suspension (Ride)	Suspension (Shock)
w1 = 12.5 ton	p1 = 445 hp	v1 = standard	o1 = standard
w3 = 16.5 ton	p3 = 500 hp	v3 = improved standard	
w5 = 22.5 ton	p5 = 600 hp	v5 = independent	

LVSR Speed Performance in the Philippines Trails



Payload Weight	Engine Power	Suspension (Ride)	Suspension (Shock)
w1 = 12.5 ton	p1 = 445 hp	v1 = standard	o1 = standard
w3 = 16.5 ton	p3 = 500 hp	v3 = improved standard	
w5 = 22.5 ton	p5 = 600 hp	v5 = independent	

LVSR NOGO Performance in the Philippines Off-Road



Payload Weight	Engine Power	Suspension (Ride)	Suspension (Shock)
w1 = 12.5 ton	p1 = 445 hp	v1 = standard	o1 = standard
w3 = 16.5 ton	p3 = 500 hp	v3 = improved standard	
w5 = 22.5 ton	p5 = 600 hp	v5 = independent	

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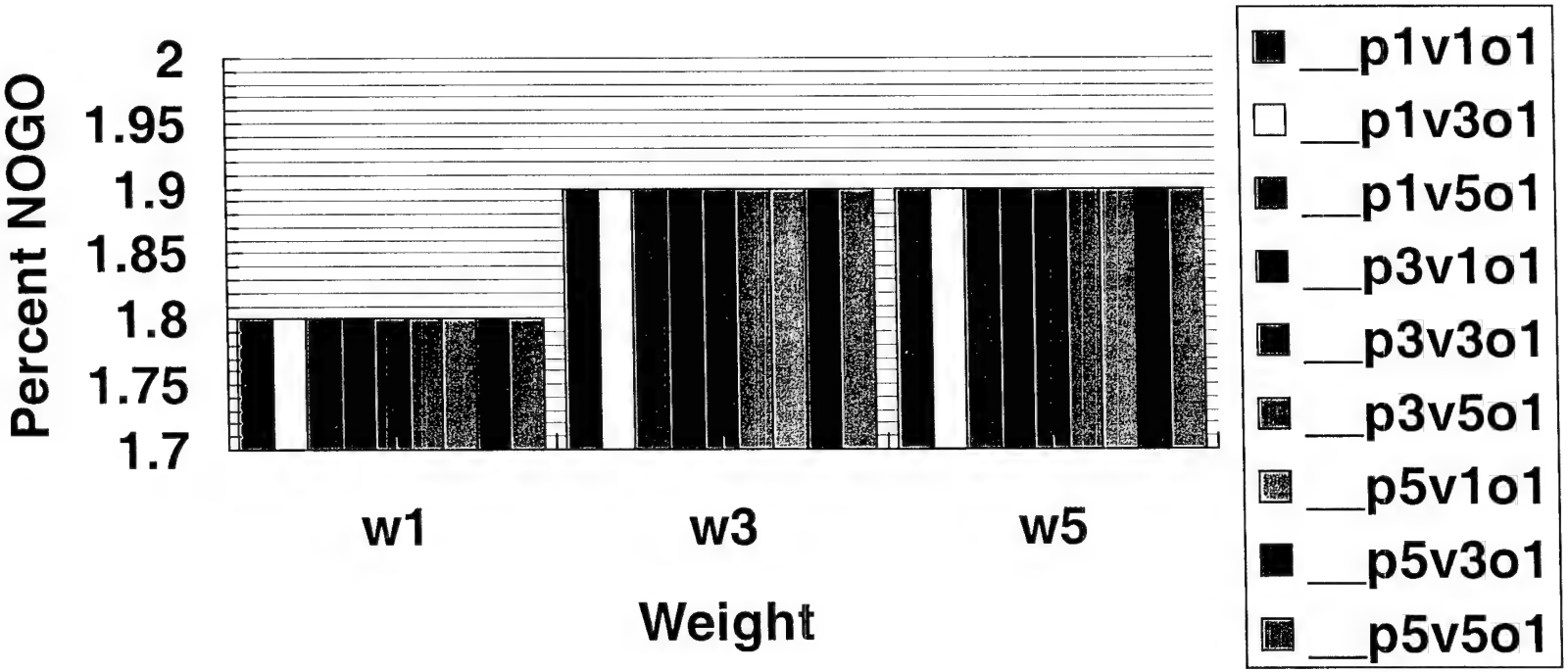
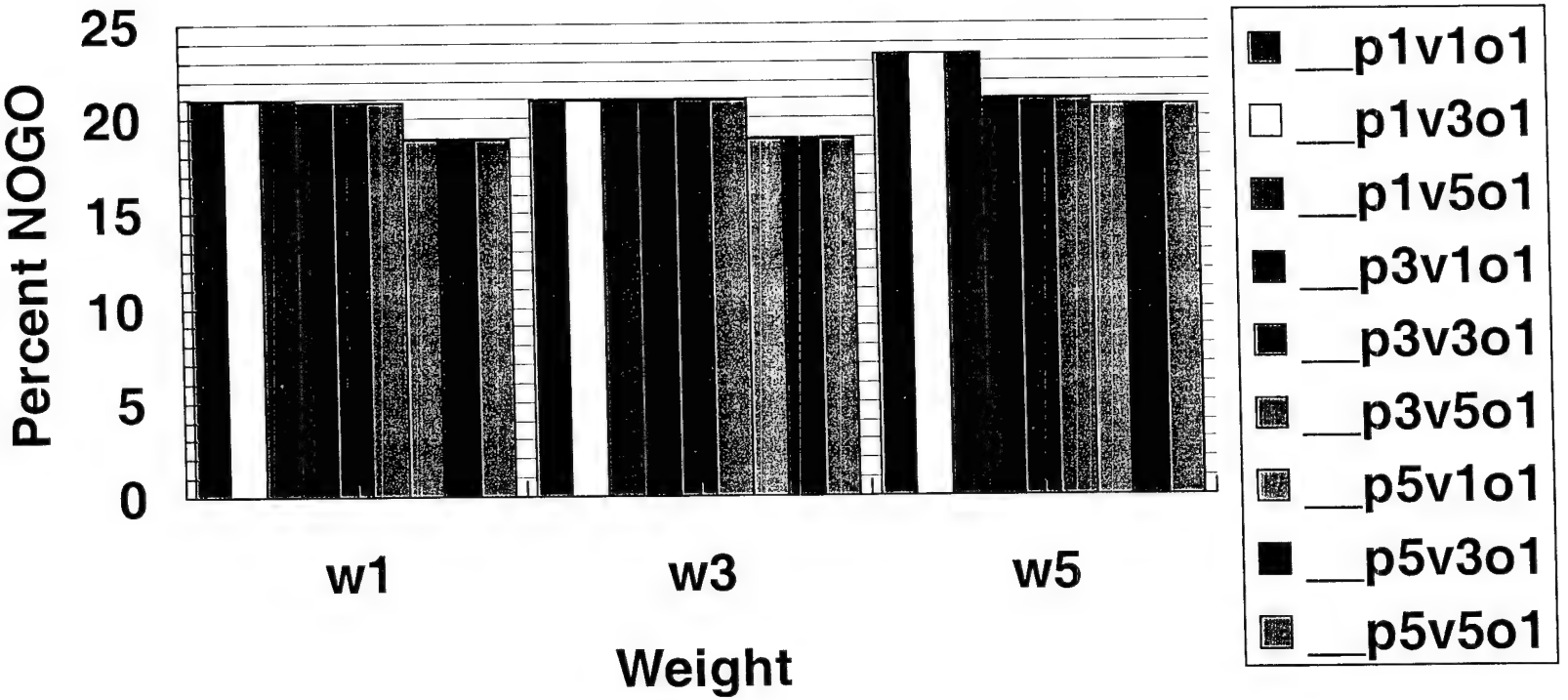
LVSR NOGO Performance in the Philippines On-Road



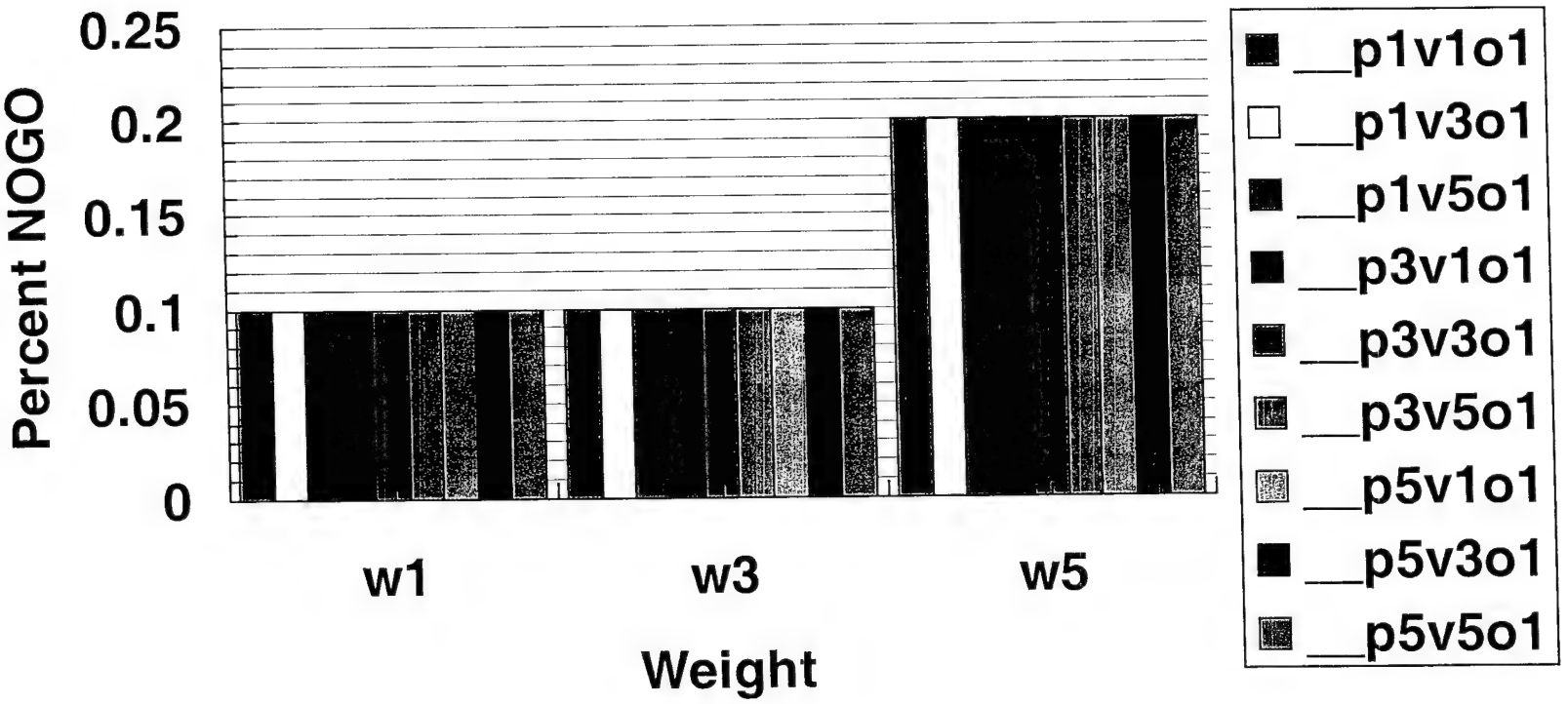
Payload Weight	Engine Power	Suspension (Ride)	Suspension (Shock)
w1 = 12.5 ton	p1 = 445 hp	v1 = standard	o1 = standard
w3 = 16.5 ton	p3 = 500 hp	v3 = improved standard	
w5 = 22.5 ton	p5 = 600 hp	v5 = independent	

LVSR NOGO Performance in Korea
Off-Road



Payload Weight	Engine Power	Suspension (Ride)	Suspension (Shock)
w1 = 12.5 ton	p1 = 445 hp	v1 = standard	o1 = standard
w3 = 16.5 ton	p3 = 500 hp	v3 = improved standard	
w5 = 22.5 ton	p5 = 600 hp	v5 = independent	

LVSR NOGO Performance in Kuwait Off-Road



Payload Weight	Engine Power	Suspension (Ride)	Suspension (Shock)
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w3 = 16.5 ton	p3 = 500 hp	v3 = improved standard	
w5 = 22.5 ton	p5 = 600 hp	v5 = independent	

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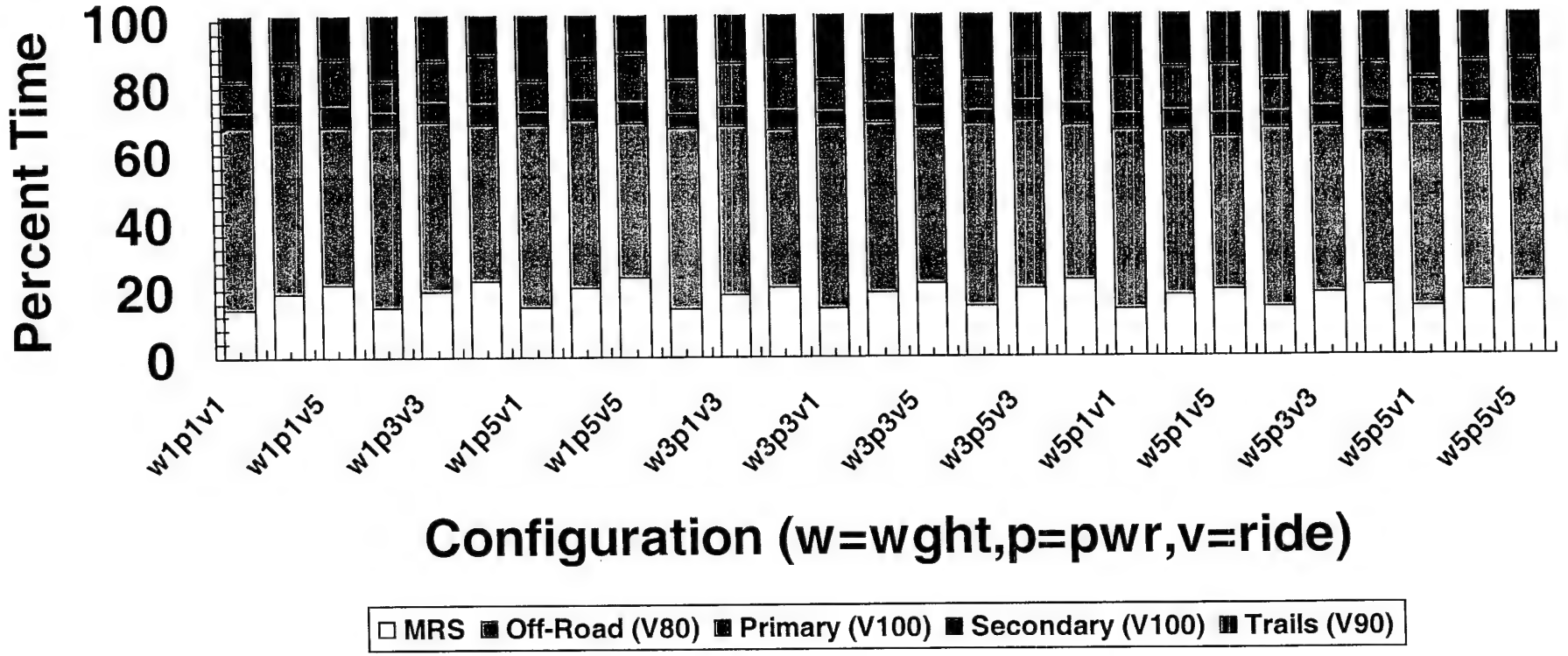
LVSR Percent Times Off-Road and On-Road
Philippines, Mindanao Dry Normal



Waterways Experiment Station

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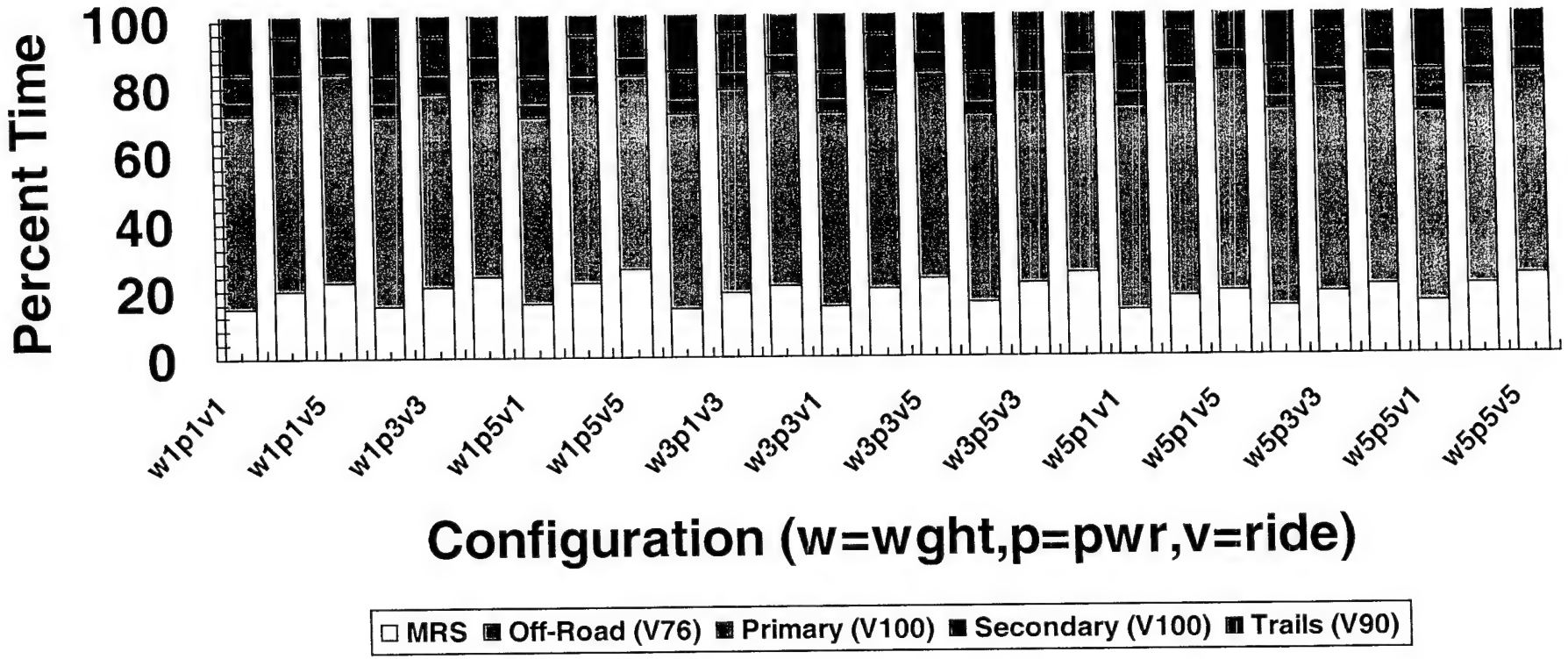
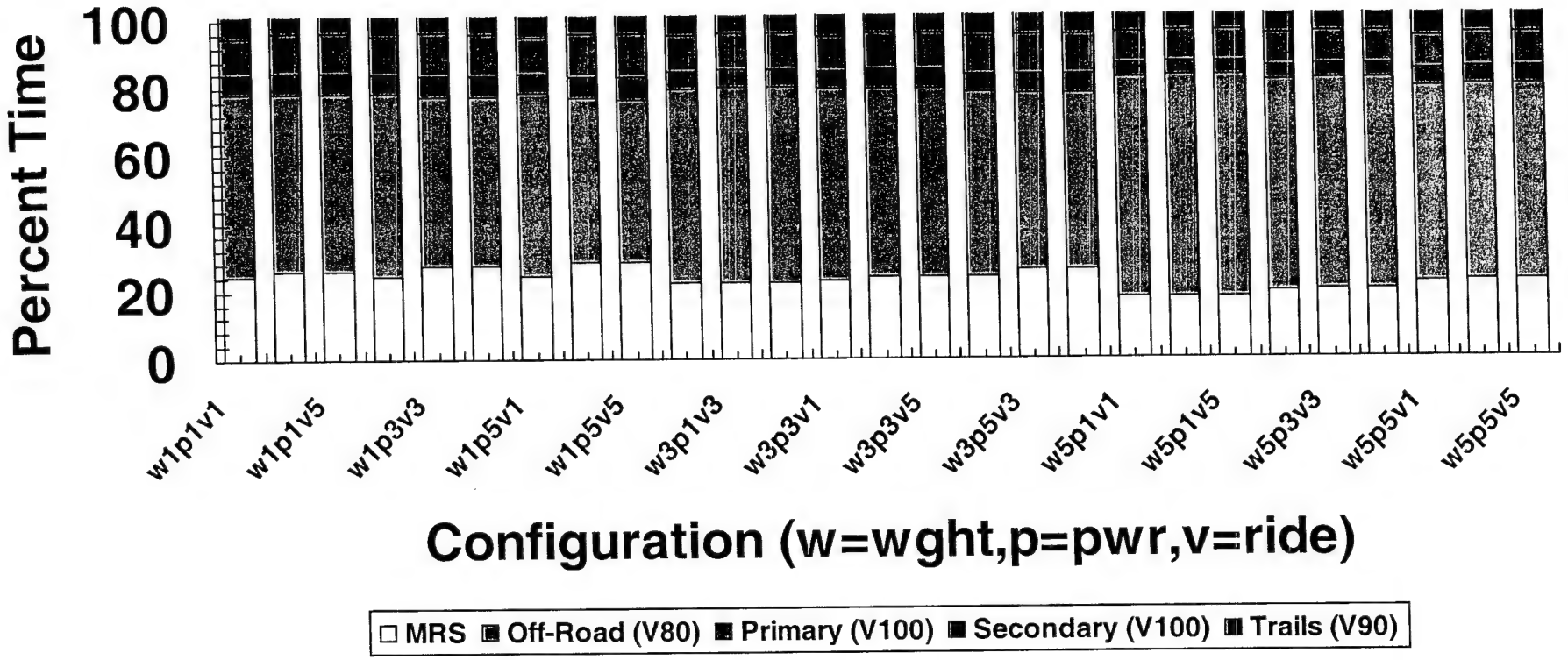
LVSR Percent Times Off-Road and On-Road
Korea, 3421i Dry Normal



Waterways Experiment Station

LVSR Percent Times Off-Road and On-Road
Kuwait, 5546i Dry Normal



Waterways Experiment Station

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Response: MRS

Summary of Fit

RSquare	0.978756
RSquare Adj	0.957774
Root Mean Square Error	0.838613
Mean of Response	20.07593
Observations (or Sum Wgts)	162

Parameter Estimates

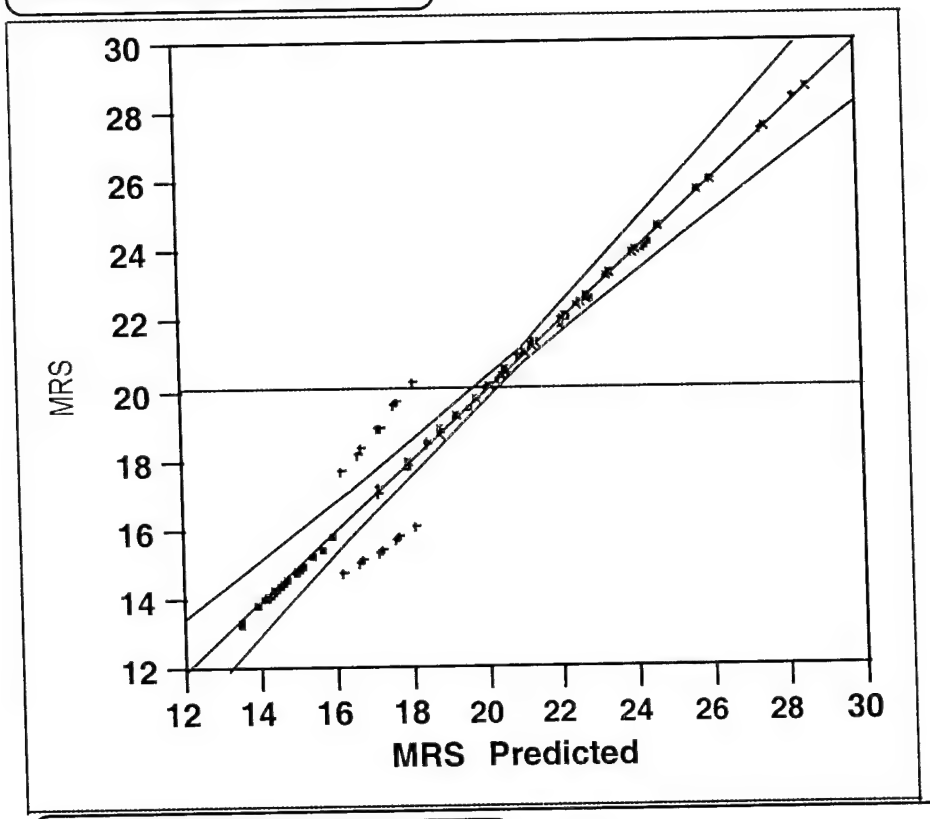
Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
Country	2	2	953.13000	677.6400	<.0001
Weight	2	2	296.84333	211.0446	<.0001
Country*Weight	4	4	141.73444	50.3840	<.0001
Power	2	2	132.25593	94.0291	<.0001
Country*Power	4	4	15.49407	5.5079	0.0006
Weight*Power	4	4	6.90296	2.4539	0.0523
Country*Weight*Power	8	8	5.08037	0.9030	0.5182
Ride	2	2	794.48481	564.8492	<.0001
Country*Ride	4	4	233.43407	82.9815	<.0001
Weight*Ride	4	4	22.88074	8.1337	<.0001
Country*Weight*Ride	8	8	4.69037	0.8337	0.5757
Power*Ride	4	4	13.82370	4.9141	0.0013
Country*Power*Ride	8	8	1.84519	0.3280	0.9530
Weight*Power*Ride	8	8	0.35963	0.0639	0.9998
Country*Weight*Power*Ride	16	16	1.55148	0.1379	1.0000

= significant interaction between factors (Prob >F is < .05)

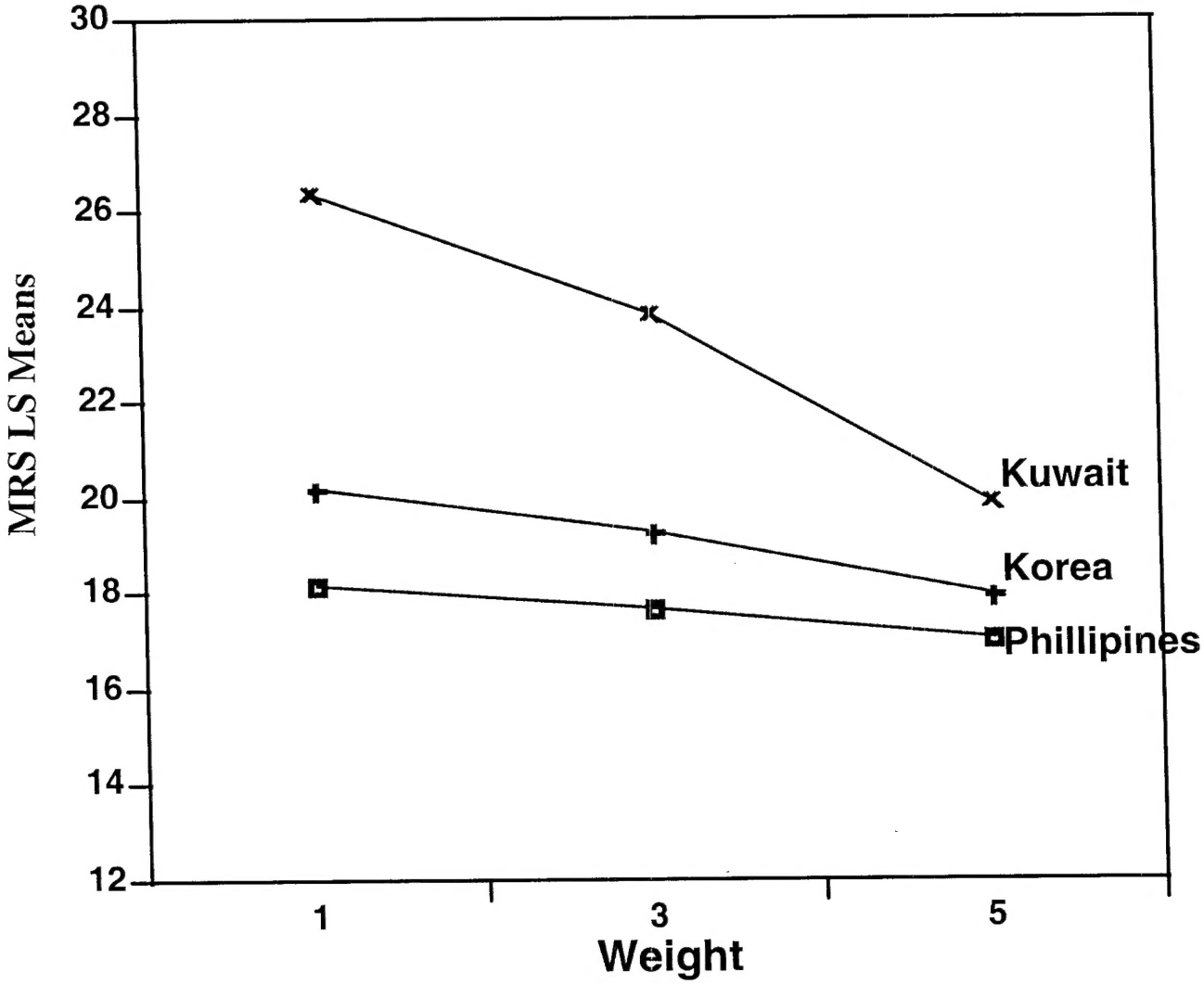
= significant factor influencing mrs (Prob >F is <.05)

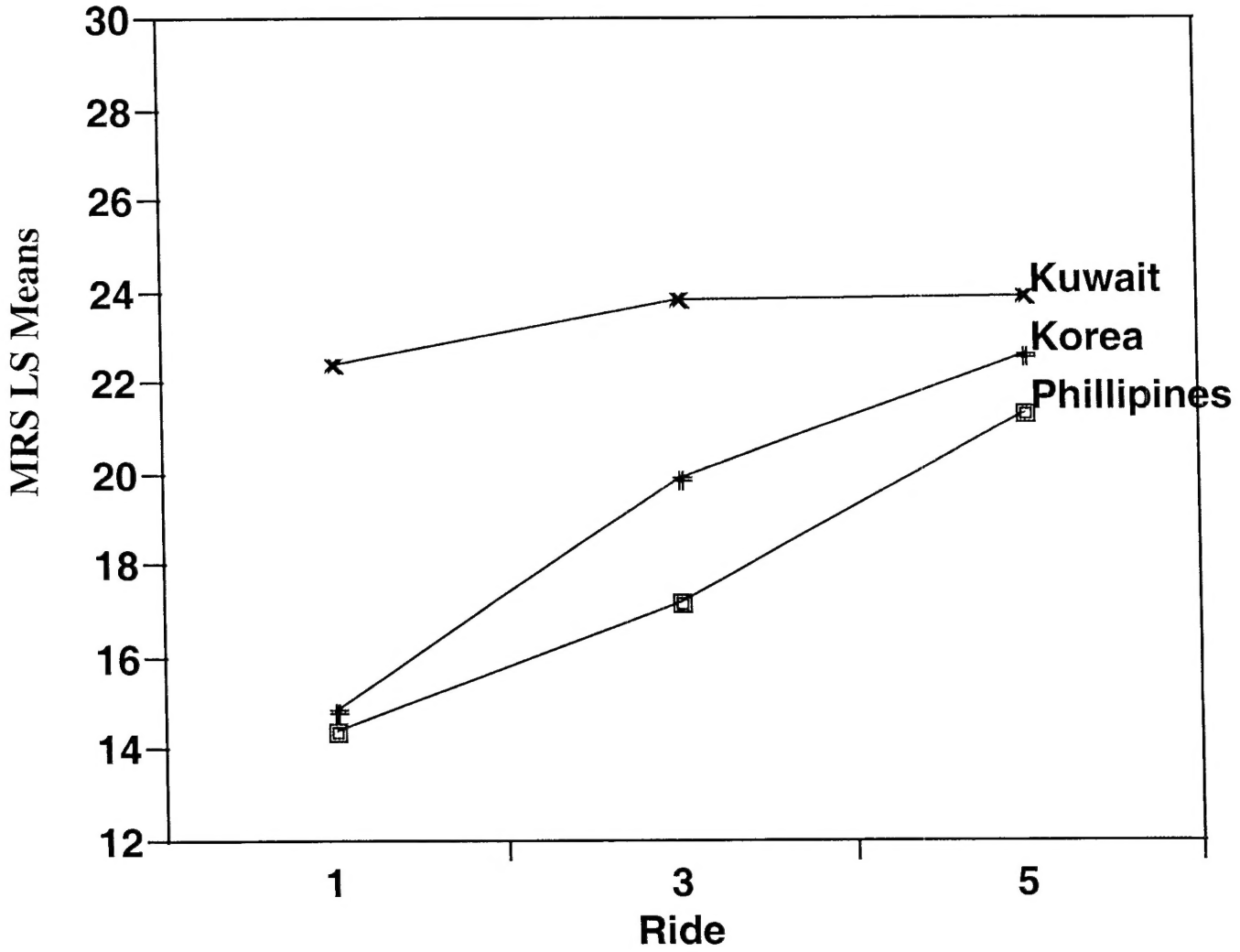
Whole-Model Test

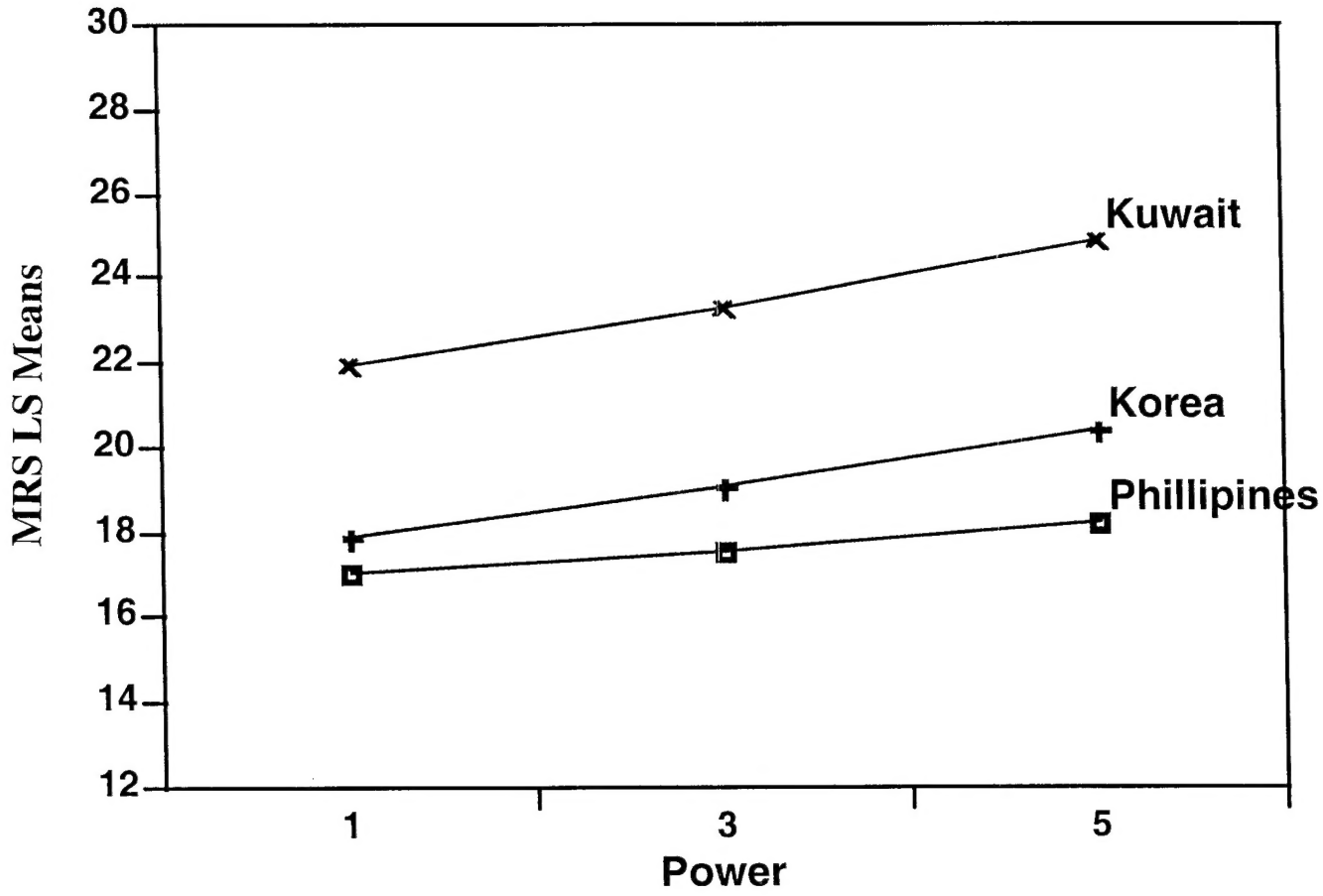


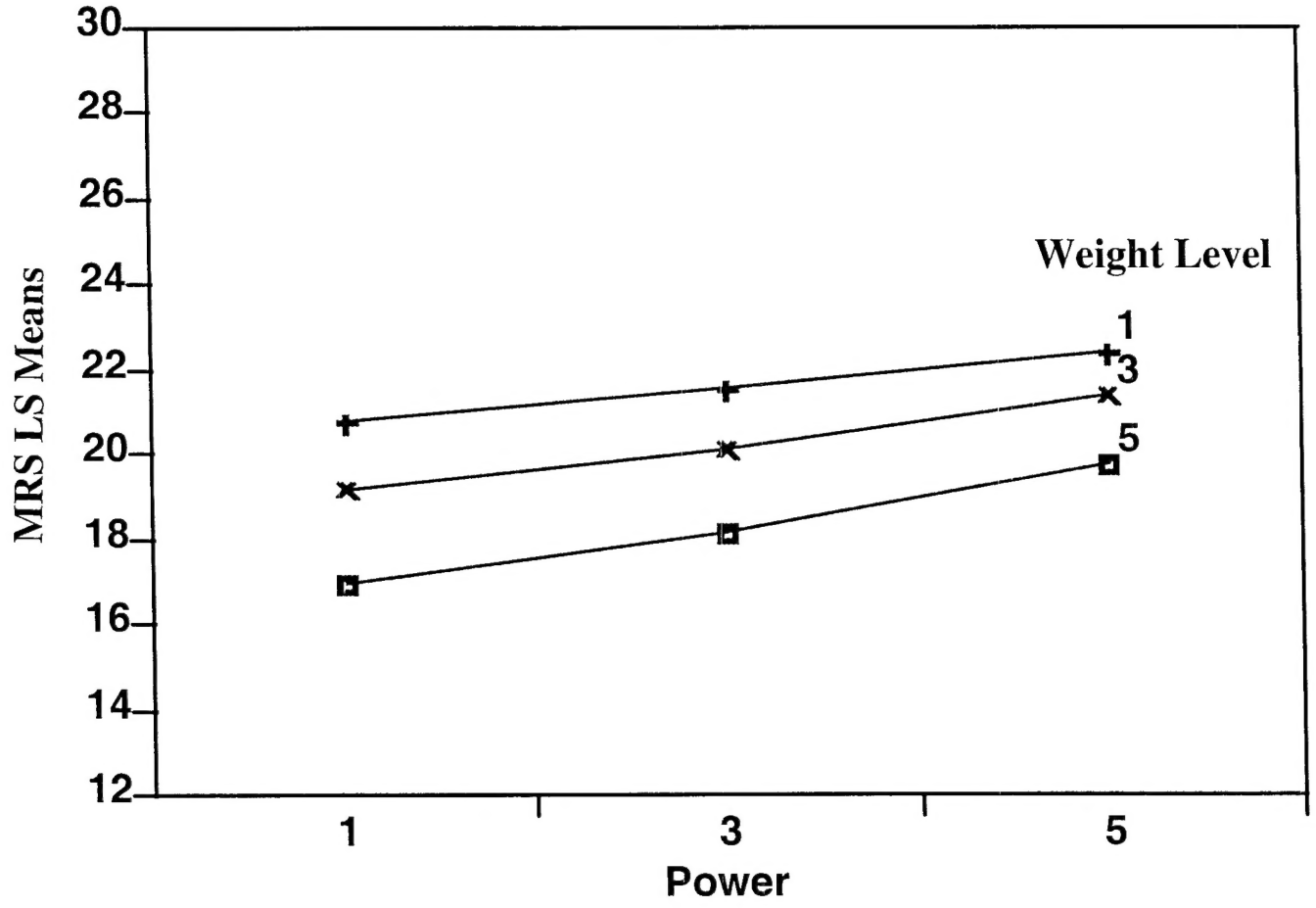
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	80	2624.5111	32.8064	46.6482
Error	81	56.9650	0.7033	Prob>F
C Total	161	2681.4761		<.0001


30
28
26
24
22
20
18
16
14
12
MRS LS Means
Kuwait
Korea
Phillipines
1
3
5
Weight


30
28
26
24
22
20
18
16
14
12
MRS LS Means
1
3
5
Ride
Kuwait
Korea
Phillipines


30
28
26
24
22
20
18
16
14
12
MRS LS Means
Kuwait
Korea
Phillipines
1
3
5
Power


30
28
26
24
22
20
18
16
14
12
MRS LS Means
Weight Level
1
3
5
1
3
5
Power